# LOAN DOCUMENT

PHOTOGRAPH THIS SHEET

DTIC ACCESSION NUMBER

LEVEL

0

INVENTORY

A Life-Cycle Inventory . . . .

DOCUMENT IDENTIFICATION

JAN 98

**DISTRIBUTION STATEMENT A**
Approved for Public Release
Distribution Unlimited

DISTRIBUTION STATEMENT

H A N D L E W I T H C A R E

| ACCESSION FOR | |
|---|---|
| NTIS GRA&I | ☑ |
| DTIC TRAC | ☐ |
| UNANNOUNCED | ☐ |
| JUSTIFICATION | |
| | |
| | |
| | |
| BY | |
| DISTRIBUTION/ | |
| AVAILABILITY CODES | |
| DISTRIBUTION | AVAILABILITY AND/OR SPECIAL |
| A-1 | |

DISTRIBUTION STAMP

DATE ACCESSIONED

DATE RETURNED

19990609 031

DATE RECEIVED IN DTIC

REGISTERED OR CERTIFIED NUMBER

PHOTOGRAPH THIS SHEET AND RETURN TO DTIC-FDAC

DTIC FORM JUN 90 70A

DOCUMENT PROCESSING SHEET

PREVIOUS EDITIONS MAY BE USED UNTIL STOCK IS EXHAUSTED.

LOAN DOCUMENT

PP304

United States
Environmental Protection
Agency

Office of Research and
Development
Cincinnati, OH 45268

EPA
January 1998

# A Life-Cycle Inventory-Based Comparison of an RDX-Based and a TNAZ-Based GBU-24 Munition

| **REPORT DOCUMENTATION PAGE** | *Form Approved OMB No. 074-0188* |
|---|---|



| **1. AGENCY USE ONLY (Leave blank)** | **2. REPORT DATE** January 1998 | **3. REPORT TYPE AND DATES COVERED** |
|---|---|---|

**4. TITLE AND SUBTITLE**
A Life-Cycle Inventory-Based Comparison of an RDX-Based and a TNAZ-Based GBU-24 Munition

**5. FUNDING NUMBERS**
CR822956

**6. AUTHOR(S)**
D. Tolle, B. Vigon, D. Evers, S. Ricci

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
Battelle Columbus Laboratories
Columbus, OH

**8. PERFORMING ORGANIZATION REPORT NUMBER**
N/A

**9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
SERDP
901 North Stuart St. Suite 303
Arlington, VA 22203

**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**
N/A

**11. SUPPLEMENTARY NOTES**
The EPA through its Office of Research and Development funded and managed the research described here under Cooperative Research Grant No. CR822956 to Battelle. 

**12a. DISTRIBUTION / AVAILABILITY STATEMENT**
Approved for public release: distribution is unlimited.

**12b. DISTRIBUTION CODE**
A

**13. ABSTRACT *(Maximum 200 Words)***
US DoD policy has evaluatied environmental considerations to an equivalent level of importance with cost and performance. Thus, with sponsorship from SERDP, the DoD, DOE, and EPA have cooperated in a program to develop technologies for clean production of propellants, energetics, and pyrotechnic (PEP) materials. Since the PEP program framework is strongly oriented around life-cycle assessment (LCA), a baseline life cycle inventory (LCI) of the guided bomb unit-24 (GBU-24) made with RDX explosives was conducted prior to this study in order to demonstrate the LCA approach.

The primary goals of this project were to develop and demonstrate the use of LCAas a ,eams of comparing alternative PEP materials. A secondary goal was to produce an LCI for both the RDX-based and TNAZ-based munitions so that further work on improving the environmental footprint might take place.

In summary, based on a "less is best" comparison across the broad range of comparators, such as amount of listed (Federally regulated) waste or total energy consumption, the RDX-system appears to currently offer the least environmental dis-benefits. If some qualitative adjustments are made in the LCI to account for data quality, the RDX-based GBU-24 is still less environmentally harmful, but the gap between the systems is closed.

**14. SUBJECT TERMS**

| | | |
|---|---|---|
| GBU-24 | life-cycle assessment | LCA |
| life cycle inventory | SERDP | |
| LCI | SERDP Collection | |

**15. NUMBER OF PAGES**

**16. PRICE CODE** N/A

| **17. SECURITY CLASSIFICATION OF REPORT** | **18. SECURITY CLASSIFICATION OF THIS PAGE** | **19. SECURITY CLASSIFICATION OF ABSTRACT** | **20. LIMITATION OF ABSTRACT** |
|---|---|---|---|
| unclass. | unclass. | unclass. | UL |

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

EPA Report Number
January 1998

# A Life-Cycle Inventory-based Comparison of an RDX-Based and a TNAZ-Based GBU-24 Munition

by

D. Tolle
B. Vigon
D. Evers
S. Ricci

Battelle Columbus Laboratories
Columbus, OH 43201

Project Officer
Kenneth R. Stone
U.S. Environmental Protection Agency
National Risk Management Research Laboratory
Cincinnati, OH 45268

CR822956

National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

Printed on Recycled Paper

## NOTICE

The U.S. Environmental Protection Agency through its Office of Research and Development funded and managed the research described here under Cooperative Research Grant No. CR822956 to Battelle. A peer review was conducted at the end of the study on the final report. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.


## ABSTRACT

U.S. Department of Defense (DoD) policy has elevated environmental considerations to an equivalent level of importance with cost and performance. Thus, with sponsorship from the Strategic Environmental Research and Development Program (SERDP), the DoD, U.S. Department of Energy (DOE), and U.S. Environmental Protection Agency (EPA) have cooperated in a program to develop technologies for clean production of propellants, energetics, and pyrotechnic (PEP) materials. Since the PEP program framework is strongly oriented around life-cycle assessment (LCA), a baseline life cycle inventory (LCI) of the guided bomb unit-24 (GBU-24) made with RDX explosives was conducted prior to this study in order to demonstrate the LCA approach.

The primary goals of this project were to develop and demonstrate the use of LCA as a means of comparing alternative PEP materials. A secondary goal was to produce an LCI for both the RDX-based and TNAZ-based munitions so that further work on improving the environmental footprint might take place.

In summary, based on a "less is best" comparison across a broad range of comparators, such as amount of listed (Federally regulated) waste or total energy consumption, the RDX-system appears to currently offer the least environmental dis-benefits. If some qualitative adjustments are made in the LCI to account for data quality, the RDX-based GBU-24 is still less environmentally harmful, but the gap between the systems is closed.

## ACKNOWLEDGMENTS

The authors acknowledge the use of life-cycle inventory data collected under the SERDP Program in the form of reports by J.K. Ostic and others from Los Alamos National Laboratory and L. Brown from Holston Army Ammunition Plant.

Also gratefully acknowledged is the continued project support for LCA methods development and report review by staff in the Sustainable Technology Division, National Risk Management Research Laboratory, U.S. Environmental Protection Agency, especially Mr. Kenneth Stone, Mr. James Bridges, and Ms. Jane Bare.

This page left intentionally blank.

# Contents

# Tables



# Figures

# Acronyms and Abbreviations

| | |
|---|---|
| AHP | Analytical Hierarchy Process |
| AIRS | Aerometric Information Retrieval System |
| AIRS EXEC | AIRS Executive |
| AP | Acidification potential ("acid rain") |
| BCF | bio-concentration factor |
| BOD | biochemical oxygen demand |
| CAA | Clean Air Act |
| CIS | Chemical Information Systems |
| COCO | contractor-owned/contractor-operated |
| COD | chemical oxygen demand |
| CWA | Clean Water Act |
| DoD | Department of Defense |
| DOE | Department of Energy |
| EC | Expert Choice™ |
| EIA | DOE's Energy Information Administration |
| EIS | Environmental Impact Statement |
| EPA | U.S. Environmental Protection Agency |
| EPCRA | Emergency Planning and Community Right-to-Know Act |
| GBU-24 | Guided Bomb Unit (Earth penetrator bomb; Navy version is B/B) |
| GOCO | government-owned/contractor-operated |
| GWP | global warming potential |
| HAP | hazardous air pollutant |
| HSAAP | Holston Army Ammunition Plant |
| HV | hazard value |
| IARC | International Agency for Research on Cancer |
| IPPD | integrate product and process development |
| ISO | International Organization of Standards |
| LCA | life-cycle assessment |
| LCI | life-cycle inventory |
| LCIA | life-cycle impact assessment |
| LCImA | life-cycle improvements assessment |
| MCAAP | McAlester Army Ammunition Plant |
| NAAQS | National Ambient Air Quality Standards |
| NEPA | National Environmental Policy Act |
| NSWC | Naval Surface Warfare Center |
| ODP | Ozone Depletion potential |
| PCB | polychlorinated biphenals |
| PCS | permit compliance system |
| PEP | propellants, energetics, and pyrotechnics |
| PM10 | particulate <10 microns aerodynamic diameter |
| POCP | photochemical oxidant creation potential ("smog") |
| QSAR | quantitative structure activity relationship |
| RCRA | Resource Conservation and Recovery Act |

| | |
|---|---|
| R&D | research and development |
| RDX | trimethylenetrinitramine explosive |
| SAR | structure activity relationship |
| SETAC | Society of Environmental Toxicology and Chemistry |
| SERDP | Strategic Environmental Research and Development Program |
| TDS | total dissolved solids |
| TPY | tons per year |
| TRI | toxic release inventory |
| TSCA | Toxic Substance Control Act |
| TSS | total suspended solids |
| VOC | volatile organic compound |
| WOE | weight-of-evidence |

# 1.0 Introduction

While the greening of weaponry may seem contradictory, it is not. Much of the weaponry prepared for the U.S. Department of Defense (DoD), especially larger items, is never consumed in the act of warfare, but is only a deterrent. As long as it remains a deterrent, preparing, maintaining, and disposing of (old or out-of-date) weaponry are acts through which humans and the environment interact with the weaponry and the resulting input or output streams. These activities, or the resulting emissions and consumption, are an argument for the greening of weaponry. In fact, current DoD policy has elevated environmental considerations to an equivalent level of importance with cost and performance (Perry, 1994).

The Strategic Environmental Research and Development Program (SERDP) is a cooperative effort between the DOD and the Department of Energy (DOE) to investigate Clean Agile Manufacturing of Propellants, Explosives, and Pyrotechnics. Coupled with DoD policy initiatives (outlined in 1994 by then Secretary Perry), the SERDP activity seeks to investigate and develop new and improved materials and processes that are intended to provide pollution prevention benefits of 50 percent to 90 percent reduction in Federally-regulated wastes. Within the diagnostic and analytical component of this effort, several evaluative tools and techniques are being evaluated, adapted for use in the DoD setting, and eventually exported to the weapons system design and development teams for application as routine procedures in system acquisition.

With these goals in mind and in cooperation with the US EPA through the Life Cycle Engineering and Design Project, SERDP set out to investigate the usefulness of life cycle assessment (LCA) methods to assess the greenness of a weapon system through a demonstration project. The goals of this study are two-fold. One, the application of LCA to provide a key part of the information basis for improvements is to be demonstrated. Two, the general approach to life-cycle improvement assessment, as adapted to DoD applications, is to be developed and ultimately disseminated to the users. The munition chosen for the study was the GBU-24 Earth-Penetrating Bomb. Reasons for choosing this munition include: 1) substitutes for the RDX-based explosive core are currently being investigated; trinitroazetidine (TNAZ) is one compound being considered, 2) other complementary manufacturing improvements are under development, and 3) Los Alamos National Laboratory has previously prepared an extensive systems model of the manufacturing operations and environmental profile for the RDX-based GBU-24.

Life Cycle Assessment (LCA) is a holistic method for examining the impact of a product or process on the environment. In an LCA the act of producing or processing is linked mathematically with activities occurring upstream (prior to the process of interest) and downstream (after the product of interest). These mathematical links allow the analyst to relate the contribution of the product or process, as well as each upstream or downstream contributing or supporting process, to the net system emissions or consumption resulting from the act of producing and using a product or process. The International Standards Organization (ISO) has developed two standards governing LCA. Standard 14040 describes the general principles and framework of LCA and Standard 14041 provides more detailed information on goal and scope definition and inventory analysis.

An LCA typically consists of several distinct phases. The first phase is Goals, Scope, and Boundary Definition. Here the purpose(s), objective(s), or question(s) to be answered through conduct of the LCA are defined, as is the extent of the system to be modeled — what processes are or are not intended to be included, i.e., the system boundary. According to the ISO standard, in defining the scope, the following items shall be considered and clearly described:

- Function
- Systems to be studied
- Allocation procedures
- Assumptions
- Initial data quality requirements
- Type and format of study report
- Functional unit
- System boundaries

- Data requirements
- Limitations
- Type of critical review (if any).

The second phase is the Life Cycle Inventory (LCI), which is the tabulation of the emissions and consumption associated with a product or process. Life Cycle Impact Assessment (LCIA) is the third phase. Here emissions or consumption terms are linked to environmental problems such as Global Warming Potential, Resource Depletion, or Human Health. The final phase is Interpretation. During this phase, the systems data are analyzed to determine which materials and processes contribute most to the results and to identify aspects in which the baseline and alternative systems are or are not discernibly different. These phases are interrelated and iterative. Life Cycle Improvements Assessment (LCImA) is but one of a number of uses to which the interpretation might be directed. Here the results of the LCI and LCIA are interpreted and qualitative evaluations of potential environmental improvements are identified.

For this improvement assessment, only the the LCI stage was conducted. These activities were conducted in accord with the U.S. EPA technical guidance manual (1993) for LCI studies. A parallel study (U.S. EPA, 1997b) on the life cycle impacts associated with the RDX-based GBU-24 system was used as a reference in estimating the impacts associated with the TNAZ-based GBU-24. The inventory data for the RDX-based GBU-24 are identical for each study.

## 2.0 Goals, Scope and Boundary Definition

### Goal Definition

During the period 1993-95 the baseline resource use and pollution burdens for the life cycle of the GBU 24 B/B earth penetrator bomb unit were examined using a combination of primary data collected from the production sites and secondary-modeled data and literature information for commercial operations such as steel and ammonia production. This study was conducted by the Los Alamos National Laboratory. This information showed certain pollutional characteristics associated with both the batch production of the RDX and aluminum fill used in the GBU24 and the environmental burdens associated with on-site– and off-site–produced electricity and steam. Several alternative materials and processes are in various stages of development and could function as either replacement components, alternative processing technologies, or substitute materials.

The goal of this life cycle inventory study is to compare one such alternative energetic material, trinitroazetidine (TNAZ), with the baseline RDX (royal demolition explosive) energetic material. Although the primary implementation of this goal involved the development of data modules pertaining to TNAZ production, certain other changes, necessitated by the different physical and chemical properties of TNAZ, were required to be introduced into the baseline. These other differences are summarized below and discussed in greater detail further in the body of the inventory report.

TNAZ, like RDX, is compounded into the explosive mix and fill material (CXM7 and PBXN109 in the case of RDX) by blending it with other ingredients. It is likely that in actual production the blend would be tailored to the specific characteristics of TNAZ. However, for purposes of this inventory, which was configured to allow examination of TNAZ as a "drop-in" replacement for RDX, the fill material selected was an 80:20 mixture of TNAZ and aluminum, identical to that used in the current GBU24.

Production of TNAZ uses very different starting materials than RDX. Hence, the upstream operations were characterized on the basis of commercial production activities and secondary data sources. Depending on the amounts produced, actual production may determine that certain of the precursors could be produced by government-owned, contractor-operated (GOCO) facilities. Such GOCO facilities could be located at the existing sites for production of RXD-based munitions or at a greenfield site.

- In the original baseline inventory, the time distribution of resource consumption and emissions was based on assumptions about the peacetime production rates and the expected operational obsolescence of the stockpile of GBU24. Since no logistics setting has been uniquely defined for the TNAZ-based item, it was assumed that the operational deployment activities would be performed similarly except for the actual steps in demilitarization efforts that are specific to the physical properties of TNAZ.

- TNAZ has never been produced on a commercial scale. Therefore, it is impossible to obtain resource use and emissions information from actual full-scale operations. Instead the data developed from smaller scale (1 kg to 1,000 kg) syntheses was scaled to approximately commercial engineering operations through use of process simulation and thermo-dynamic computation models to assess ancillary operational requirements.

- Due to data problems with a subcontractor, not all of the data detail specified in the preliminary goal definition and scoping were obtained. This necessitated the assumption that certain process energy requirements for a TNAZ-filled GBU would be identical to those for the current GBU. This is unlikely to be entirely the case; however, given the data deficiency no other pathway was available.

### Scope Definition

The intended scope of this study is the inventory

analysis of TNAZ as a drop-in replacement energetic fill material for RDX in a GBU-type end item. The inventory covers the cradle-to-grave activities of the alternative system in a manner similar to that of the baseline inventory. Specifically omitted are wartime deployment and stockpile replenishment and shipboard readiness activities. Also, in keeping with the boundaries of the original inventory, the resource use and emissions from RD&D activities during system development were excluded. In fact, these activities, particularly laboratory scale syntheses using alternative chemistries, engineering scale up trials, and qualification testing all have the potential to be contributory to the life-cycle profile. However, in the interest of showing the current profile for an "as-deployed" end item, these early stage contributions were omitted. All other operations from initial raw materials manufacturing to ultimate demilitarization were included in the system boundaries.

This study was conceived as including only an inventory analysis. Although an equivalency-based life-cycle impact assessment has been produced for the RDX-based item, resources did not permit a parallel effort for the TNAZ case study. Therefore, data collection and associated quality goals were specified for an inventory analysis. No external, third party critical review was identified as needed for the study. However, peer review was provided by the sponsoring organizations directly (U.S. EPA) and indirectly (U.S. Army).

The report format was designed to communicate clearly with the intended users. As noted in the introduction, there are two groups of users within the acquisition team — the process and system designers and the weapons system program managers and supervisory staff. In the former group, it is most important to illustrate the details of which activity steps are contributory to the overall environmental burdens. In the latter group, it is important to have the ability to compare the two different fill alternatives with respect to DOD-controlled versus commercial sector activity and to distinguish wastes that "count" towards the pollution prevention reduction goal (i.e., are listed wastes in RCRA, the Clean Water Act, or other legislation from the total environmental burdens), e.g., carbon dioxide contributions to global warming. These latter wastes may be used to further express general improvements in the overall environmental profile, but do not address achievement of the stated P2 goal.

## Boundary Definition

For each system, all activities from acquisition of raw materials (geologic and biotic resources) through ultimate (peace-time) disposal were included. Excepted from the system were weapon system maintenance and/or preparatory activities, for example, periodic maintenance and calibration while deployed and any military use-readiness activities. Also excepted, as noted above, were research and development activities, and testing and deployment activities.

Primary materials common to both systems include iron ore, limestone, and coal for the bomb body and crude oil and natural gas as feedstocks for chemical synthesis or as fuels. Demilitarization was different for each system. Both systems also require salt and a source of nitrogen for use in upstream synthesis operations. The systems differ in the modes of acceptable demilitarization. Physical removal of the RDX followed by burning, to reduce volume, is the disposal method for RDX. Melt-out of TNAZ for recycle into other munitions is the method modeled. In each case, the bomb body is recycled via the scrap steel recycling infrastructure. Although it may be possible to reuse the bomb body with only minor refurbishment in the case of TNAZ, this operation was not modeled.

# 3.0 System and Inventory Module Descriptions

The GBU-24 is an earth penetrator bomb equipped with a laser guidance package designed to penetrate up to 6 feet of reinforced concrete. As shown in Figure 3-1, the assembled item consists of several component and subcomponent parts. The BLU-109 bomb body is the largest physical component and contributes the majority of the material mass to the system. The other components listed were not included because they are minor in comparison and are readily reused in any event. Within the BLU-109, the bomb case itself is the largest source of material (approximately 70 percent of the total weight) and efforts are underway to evaluate ways to reduce pollution from its manufacture through recycling of the steel. Approximately 27 percent of the total comes from the explosive fill. The PBXN-109 is a blend of four components: CXM-7 explosive mix, aluminum powder, thermoset plastic binder, and miscellaneous other blending and forming agents. About 3 percent of the mass is contributed by thermal insulation applied to the bomb exterior and asphalt interior liner.

The work flow representation of the RDX-based GBU-24 life cycle is illustrated in Figure 3-2. Raw materials are sourced for the energetic materials production from commercial commodity chemical producers. The synthesis of RDX, together with the coating and blending to manufacture CXM-7, is provided by Holston Army Ammunition Plant (HSAAP) in Kingston, TN. The CXM-7 is then shipped to McAlester Army Ammunition Plant (MCAAP) in McAlester, OK. Load/assemble/pack (L/A/P) operations are performed at MCAAP, which includes blending the CXM-7 with aluminum and other additives to produce the plastic-bonded explosive used for the GBU-24. The steel bomb bodies are also shipped to MCAAP from a commercial producer (National Forge).

For the TNAZ-based munition it was assumed that a similar arrangement would be maintained. Precursor materials to the explosives are purchased from various suppliers. Munition disassembly and explosive destruction or reclamation occurs at Indian Head Naval Surface Warfare Center (IHNSWC). Currently RDX is burned and the resulting ash disposed of in a landfill. One advantage of TNAZ is that it can be reclaimed and reused a number of times. The reclamation operation was also assumed to occur at Indian Head. Each system requires transport of materials or munitions, and consumes an amount of electricity generated off-site.

For the two systems, the L/A/P operations at McAlester were assumed to be almost identical in that TNAZ was assumed to be a true "drop-in" replacement for RDX. This is not exactly the case since TNAZ has a greater energy density and, thus, needs some additional filler to increase the mass and volume of TNAZ-based explosive material in the GBU-24 in order to maintain its flight characteristics.

One other point to consider is the state of development of each of the two systems. The RDX-based munition has been produced for a number of years, hence optimization of the system with regard to yield and energy efficiency is near maximum. The TNAZ-based system is still in the lab scale/pilot scale developmental stage. While much optimization has taken place (more than an order of magnitude reduction in total waste per pound of TNAZ produced was achieved between 1993 and 1996 alone), it is thought that more will occur, especially as the system is scaled up to production quantities. The TNAZ system modeled in this LCI is a hybrid of lab and/or pilot scale developments with some potential, and highly probable, modifications to increase yield or energy efficiency, or change the input resource to those thought to be cause less environmental harm.

## RDX-Based System

A baseline inventory (LCI) of the current GBU-24 earth penetrator bomb was conducted during 1993 and 1994 (the data basis was 1992 operations). That effort attempted to adhere very closely to the LCI methodology described in Society of Environmental Toxicology and Chemistry (SETAC) and U.S. EPA technical guideline publications (U.S. EPA, 1993). Preliminary results of that analysis have been reported in several forums and publications (Ostic, 1994; Brown, 1995; Newman and Hardy, 1995) and are briefly

summarized below. Numerous organizations supplied information for the baseline effort including the following.

- Commercial Raw Materials Production, Fuels Acquisition, and Electric Power Generation: Battelle Columbus

- Intermediate/Fill Materials Production and L/A/P Operations: Holston and McAlester Army Ammunition Plants

- Use/Maintenance and Demil Operations: Naval Surface Warfare Center, and Coordination of Inventory Data Assembly: Engineering Systems Analysis Department, Los Alamos National Laboratory.

Assembly and validation of the data, together with the modeling of the system resource consumption and environmental burdens, was performed by the Technology Modeling and Analysis Group at LANL. The environmental emissions and energy and resource consumption output from this model was provided to Battelle.

Modeling of the GBU-specific manufacturing operations was performed in considerably greater detail than for the commercial sector activities. This was done for several reasons, not the least of which was the fact that the span of control of DoD for influencing such major industrial activities as steel and ammonia manufacture is limited. Table 1 illustrates the specific activities and process streams included in the LANL LCI model.

Battelle tabulated the inventory data provided by LANL in two dimensions. The first dimension was life cycle stage as Precursor production, HSAAP operations, MCAAP operations, IHNSWC operations, Transportation, Waste Management, and Electricity production, in order to relate emissions to the scope of control of the involved entities. The second dimension was regulatory status: Listed or Non-listed. Listed wastes are those explicitly mentioned in any of the following Federal environmental regulations, and are those to which the pollution prevention goals mentioned above are directed.

- Comprehensive Environmental Restoration, Compensation and Liability Act (CERCLA/Superfund)
- Toxic Substances Control Act (TOSCA)
- Clean Water Act (CWA)
- Clean Air Act and Amendments (CAAA)
- Superfund Amendments and Reauthorization Act (SARA)
- Toxics Release Inventory (TRI)
- Resource Conservation and Recovery Act (RCRA).

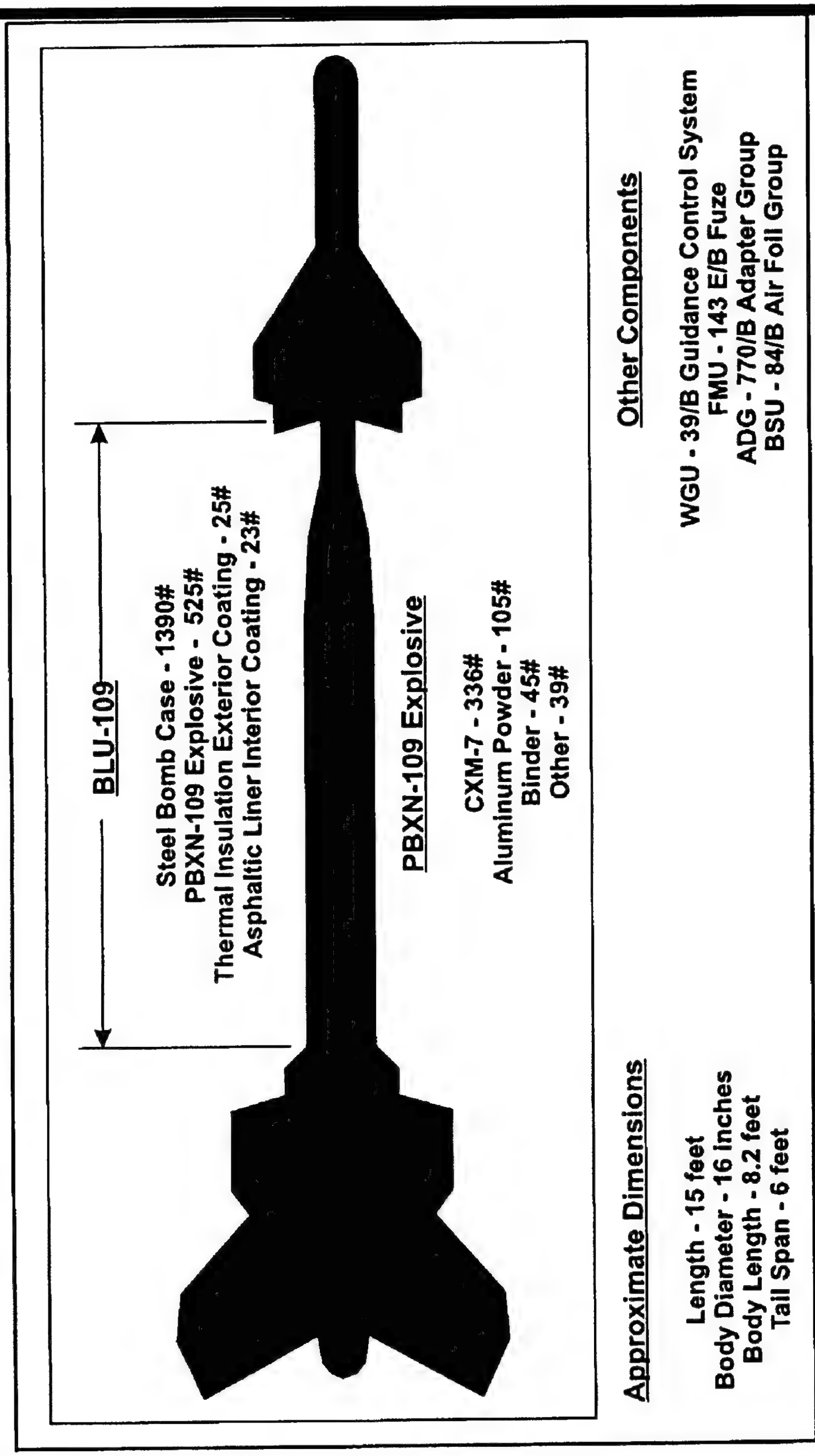


**Figure 3-1.** GBU-24: A conventional explosive earth penetrator (the functional unit for the LCA is the bomb body called BLU-109).

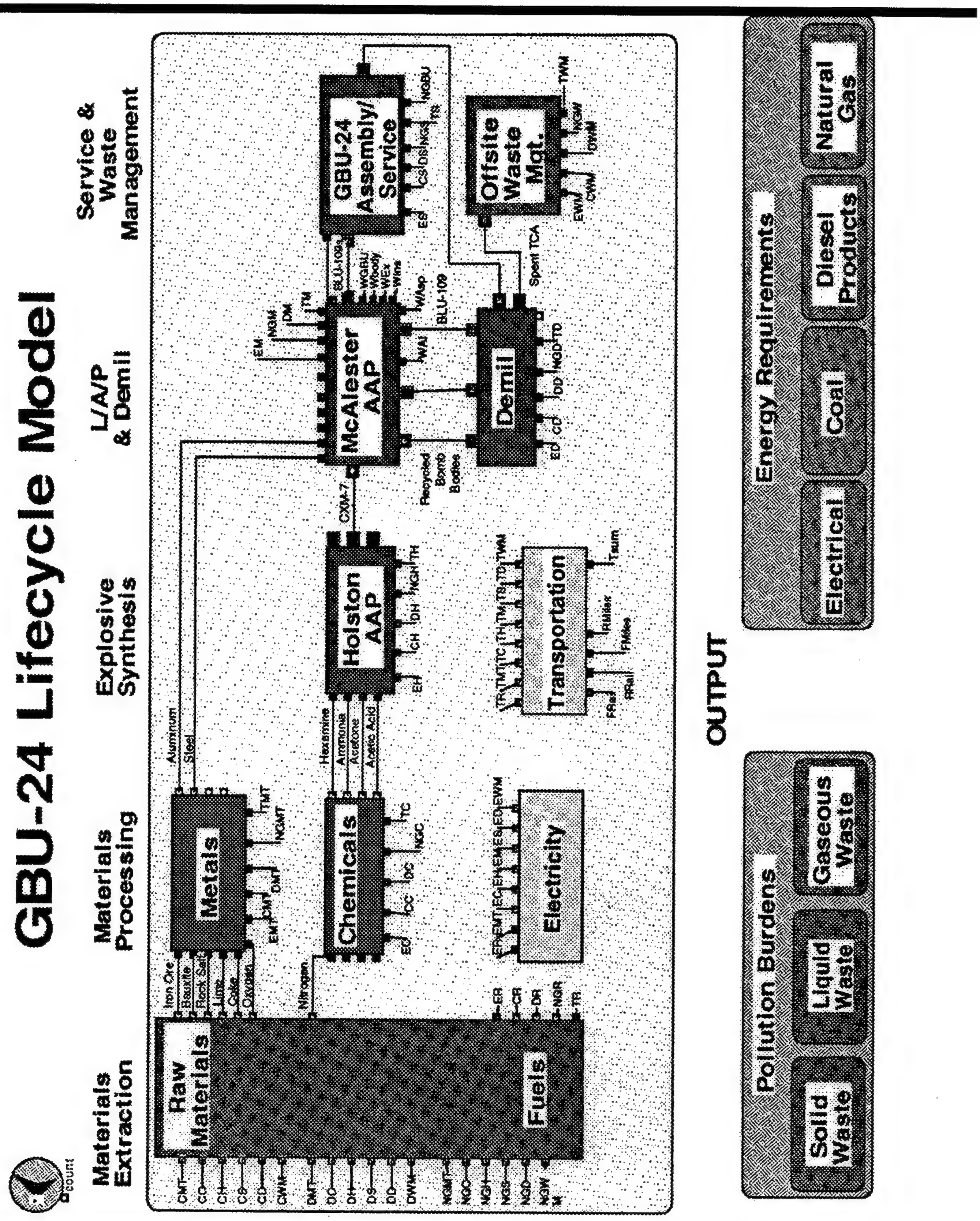


**Figure 3-2.** GBU-24 life cycle model.

**Table 3-1. Summary of Data Included in LANL RDX-based GBU-24 Life Cycle Inventory**

| Process or Activity | Consumption | | Emissions | | |
|---|---|---|---|---|---|
| | Resources | Energy | Air | Water | Solid Waste |
| **Geologic and Biotic Resource Extraction** | | | | | |
| Bauxite | Included | Included | Included | Included | Included |
| Coal | Included | Included | Included | Included | Included |
| Iron Ore | Included | Included | Included | Included | Included |
| Limestone | | Included | | | |
| Natural Gas | Included | Included | Included | Included | Included |
| Petroleum | Included | Included | Included | Included | Included |
| **Intermediate Materials Manufacture** | | | | | |
| Acetic Acid | Included | Included | Included | Included | |
| Acetone | Included | Included | Included | Included | Included |
| Aluminum | Included | Included | Included | Included | Included |
| Ammonia | Included | Included | Included | Included | |
| Coke | | Included | | | |
| Cyclohexanone | | | | | |
| Dioctyl adipate (DOA) | | | | | |
| Formaldehyde | Included | Included | Included | | |
| Hexamine | Included | Included | | | Included |
| Nitric acid | Included | Included | Included | Included | |
| Nitrogen | | Included | | | |
| Oxygen | | Included | | | |
| Propyl acetate | | | | | |
| Steel | Included | Included | Included | | Included |
| Steel Forging | Included | Included | | | |
| Trichloroethane | | | | | |
| Triethyl phosphate | | | | | |
| **Holsten AAP** | | | | | |
| Acetic acid Production | Included | Included | Included | Included | Included |
| Acetic anhydride Concentration | Included | Included | Included | Included | Included |
| Area A Steam Plant | Included | Included | Included | Included | Included |
| Explosives Plant | Included | Included | Included | Included | Included |
| Nitric acid Production | Included | Included | Included | Included | |
| Spent acid Recovery | Included | Included | Included | Included | |
| Nitric acid Concentration | Included | Included | Included | Included | |
| Nitric acid - Ammonium nitrate Production | Included | Included | Included | Included | |
| Industrial Wastewater Treatment Plant | Included | Included | | Included | Included |
| Filtered Water Production | | | | | |
| Burning Ground | | | | | |
| Incinerator | | | | | |
| **McAlester AAP** | | | | | |
| Inert Preparation | Included | Included | Included | | Included |
| Receiving | Included | Included | | | |
| Mixing | Included | Included | Included | | Included |
| Casting | Included | Included | Included | Included | Included |
| Bomb Seal | Included | Included | | Included | Included |
| Final Assembly | Included | Included | | | |
| Radiography | Included | Included | | | |
| Chemical Laboratory | Included | Included | Included | | Included |
| Boiler | Included | Included | Included | | |
| **Demilitarization** | | | | | |
| Disassembly | | Included | | | |
| Water Jet Washout | Included | Included | | Included | Included |
| Solvent Soak | Included | Included | | Included | Included |
| Burning Ground | | Included | Included | | Included |
| Water Treatment | Included | | | | |
| **Off-site Electricity Generation** | | | | | |
| Coal-fired Plant | Included | Included | Included | | Included |
| Diesel-fired Plant | Included | Included | Included | | |
| Natural gas-fired Plant | Included | Included | Included | | |
| National Grid | Included | Included | Included | Included | Included |
| **Transportation** | | | | | |
| Transportation | Included | Included | Included | Included | Included |

## TNAZ-based System

The approach to modeling the life cycle of the TNAZ-based munition was a straight-forward replacement of the appropriate processes and segments of the RDX-based system. No work had been done on modeling the TNAZ-based system, but the LANL computational framework and engine are modular so that appropriate TNAZ specific pieces could be substituted. Battelle undertook the generation of modules for precursors to TNAZ production, along with modules for demilitarization including recycling of TNAZ. This modeling effort entailed preparing process characterizations and mass balances for each needed module. Battelle subcontracted with LANL to integrate the new modules into the existing computational framework to make adjustments to the model for changes in operations and emissions at Holston and McAlester that would result upon the substitution of TNAZ into the GBU, and to provide results for a number of defined scenarios. The task of calculating process energy requirements and government-owned facility energy infrastructure changes necessary to support TNAZ manufacture and use was also subcontracted to LANL.

The modules prepared by Battelle included formaldehyde, NIB-glycerol, di-isopropylazodicarboxylate, triphenyl phosphine, acetic anhydride, tert-butylamine, sodium hydroxide, hydrochloric acid, hydrogen peroxide, isopropanol, 2-butanone (methyl ethyl ketone), sodium nitrite, potassium ferrocyanide, sodium persulfate, methyl tert-butyl ether, ferrous chloride, nitric acid, ammonium nitrate, ethanol, acetonitrile, nitrogen, deionized water, Dow 2210 antifoaming agent, and melt out of TNAZ from decommissioned munitions. Data for these modules was taken from the LANL work on RDX and from other LCIs. Some modules were developed from first principles of chemical engineering. A complete listing of calculations and data sources is given in Appendix D, while data sources and brief descriptions are given in Table 3-2.

**Table 3-2. Summary of TNAZ-Based LCI Modules Prepared by Battelle**

| Module | Data Sources | Notes |
|---|---|---|
| Formaldehyde | Brown, Hamel and Hedman, 1985 | Production of formaldehyde from methanol. |
| Methanol | Lowenheim and Moran, 1975; McGraw Hill, 1984; U.S. EPA, 1985; Kirk-Othmer, 1991; CRC Press, 1986 | Engineering calculations for methanol production as part of acetic acid production. |
| Acetic acid | Lowenheim and Moran, 1975 | Production of acetic acid from methanol. |
| Manufactured gas or Synthesis gas | Kirk-Othmer, 1964 | Production of synthesis gas from coal. |
| Nitroethane | Kirk-Othmer, 1978; W.R. Grace Co., 1992 | Co-production of nitro compounds: nitroethane, nitromethane, nitropropane, from nitrogen and light hydrocarbons. |
| Nitric acid and Ammonium nitrate | Holston Defense Corporation | Co-production of nitric acid and ammonium nitrate at Holston AAP. |
| Diisopropyldiazodicarboxylate | McGraw Hill, 1984; U.S. EPA, 1985; CRC Press, 1986. | Engineering calculations of emissions and energy and resource consumption from DIAD production. |
| Phosgene | Lowenstein and Moran, 1975; McGraw Hill, 1984; CRC Press, 1985; U. S. EPA, 1985; SRI, 1993 | Engineering calculation of emissions and energy and resource consumption for phosgene production. |
| Ammonia | U.S. EPA, 1985; U.S. DOE, 1994; U.S. EPA, 1995; U.S. DOE, 1993 | Production of fertilizer quality ammonia. |
| Sodium hydroxide | SimaPro 3.0, 1994 | Co-production of sodium hydroxide, chlorine and hydrogen via electrolysis of brine. |
| Sulfuric acid | U.S. EPA, 1995; Fertilizer Institute, 1982 | Production of sulfuric acid via the phosphate wet method. |
| Monochlorobenzene | Lowenheim and Moran, 1974; McGraw Hill, 1984; U.S. EPA, 1985; Kirk-Othmer, 1964; U.S. ITC, 1994 | Engineering calculation of emissions and resource and energy consumption for monochlorobenzene production. |
| Benzene | SimaPro 3.0, 1994 | European production of technical grade benzene. |
| Isopropanol | Lowenheim and Moran, 1975; McGraw Hill, 1984; U.S. EPA, 1985; SRI, 1993; U.S. ITC, 1994; CRC Press, 1985 | Engineering calculation of emissions and resource and energy consumption from isopropanol production. |
| Propylene | SimaPro 3.0 | European production of monomer quality propylene. |
| Phosphorus trichloride | | Engineering calculations of emissions and energy and resource consumption for phosphorus trichloride production. |
| Acetic anhydride | Holston Defense Corporation | Production of acetic anhydride at Holston AAP. |
| Acetic acid | Lowenheim and Moran, 1975; McGraw Hill, 1984; U.S. EPA, 1985; Kirk-Othmer, 1964; CRC Press, 1986 | Engineering calculation of emissions and resource and energy consumption for acetic acid production. |
| Methyl Ethyl Ketone | Lowenheim and Moran, 1975; McGraw Hill, 1984; U.S EPA, 1985; SRI, 1993; U.S. ITC, 1994; CRC Press, 1986 | Engineering calculation of emissions and resource and energy consumption for MEK production. |
| Butylene | SimaPro 3.0, 1994 | European production of monomer quality butylene. |

| Module | Data Sources | Notes |
|---|---|---|
| Methyl tert-Butyl Ether | Lowenheim and Moran, 1975; Mc Graw Hill, 1985; U.S. EPA, 1985; SRI, 1993; U.S. ITC, 1994; CRC Press, 1986 | Engineering calculation of emissions and resource and energy consumption during MTBE production. |
| Ethanol (via Fermentation from Corn Sugars) | Numerous | Production and harvesting of corn. Transportation of corn to processing center. Milling of corn to separate sugars and starches from fiber. |
| Acetonitrile | Lowenheim and Moran, 1975; Mc Graw Hill, 1985; U.S. EPA, 1985; SRI, 1993; U.S. ITC, 1994; CRC Press, 1986 | Engineering calculation of emissions and resource and energy consumption during co-production of acetonitrile and acrylonitrile. |
| Demilitarization | | Engineering calculations of emissions and resource and energy consumption during demilitarization. |

A number of assumptions were made for the TNAZ - based system LCI. First, energy consumption would be similar for both the RDX-based and TNAZ-based systems so that the RDX-based energy consumption information could be used in the TNAZ-based system LCI. Second, the transportation infrastructures for the two systems were identical. Given that manufacturing operations have not been sited for the processes this appears to be a reasonable approach. If direct reuse of the bomb body proves feasible then transportation emissions and energy consumption should decrease for the TNAZ-based GBU. The third assumption was that the electricity generation emissions were also identical in the two systems. In part, these assumptions were necessary to complete the LCI because LANL was not able to provide the results of the TNAZ-based modeling in sufficient detail to allow TNAZ-specific substitutions to be developed and incorporated into the LCI and verified.

# 4.0 Results

The detailed life cycle inventories are presented in Appendices A and B for the RDX-based and TNAZ-based systems, respectively. The following tables and figures summarize and compare the results presented in Appendices A and B. For most of the results presented in the tables the wastewater emitted during production of the TNAZ-based GBU-24 has been intentionally omitted. Since *no* wastewater emission is listed for the RDX-based system the description of the wastes for the two systems is more comparable when this omission from the RDX-based system emissions is compensated for by ignoring wastewater emissions from the TNAZ-based system. The result is a comparison of the mass of contamination of the wastewater.

Table 4-1 lists Total Emissions from each of the two systems. The amounts of listed and non-listed wastes are also given. For both Total Emissions and Listed Emissions the RDX-based munition has significantly lower emissions. There is no discernable difference among the systems for Non-Listed Emissions. The results are presented in Figure 4-1.

**Table 4-1. Total Emissions from Systems (in pounds per GBU-24)**

| Emission | RDX-based GBU-24 | TNAZ-based GBU-24 |
|---|---|---|
| Listed | 1,158 | 20,733 |
| Non-Listed | 30,837 | 29,547 (1) |
| Total | 31,995 | 50,280 |

(1) Less wastewater discharge of 11,654,826 lb.

Emissions by environmental compartment also tend to favor the RDX-based system (see Table 4-2 and Figure 4-2). The exception being Air Emissions where no discernable difference exists between the systems.

**Table 4-2. Emissions from Systems by Environmental Compartment (in pounds per GBU-24)**

| Compartment | RDX-based GBU-24 | TNAZ-based GBU-24 |
|---|---|---|
| Air Emissions | 26,945 | 27,072 |
| Water Emissions | 354 | 9,176 (1) |
| Solid Wastes | 4,697 | 14,033 |

(1) Less wastewater discharge of 11,654,826 lb.

Tables 4-3 and 4-4 and Figures 4-3 and 4-4 present the results for Listed and Non-Listed Emissions by point of origin. Emissions for Transportation, Waste Management, and Off-site Electricity Production were identical for the two systems since the RDX-based system data was used for the TNAZ-based system. The RDX-based system has lower emissions of Listed Wastes during Precursor Production and at Military Facilities. Non-Listed Wastes emitted from Military Facilities are lower for the TNAZ-based system.

**Table 4-3. Listed Emissions for Each System by Point of Origin (in pounds per GBU-24)**

| Point of Origin | RDX-based GBU-24 | TNAZ-based GBU-24(1) |
|---|---|---|
| Precursors Production | 620 | 7,640 |
| Military Facilities | 364 | 12,919 |
| Transportation | 4 | 4 |
| Waste Management | 0 | 0 |
| Off-site Electricity Production | 169 | 169 |

(1) Less wastewater discharge of 11,654,826 lb.

**Table 4-4. Non-Listed Emissions for Each System by Point of Origin (in pounds per GBU-24)**

| Point of Origin | RDX-based GBU-24 | TNAZ-based GBU-24(1) |
|---|---|---|
| Precursors Production | 6,332 | 6,291 |
| Military Facilities | 7,934 | 6,685 |
| Transportation | 189 | 189 |
| Waste Management | 773 | 773 |
| Off-site Electricity Production | 15,609 | 15,609 |

(1) Less wastewater discharge of 11,654,826 lb.

Resource consumption is also much less for the RDX-based GBU-24 (see Table 4-5 and Figure 4-5). Again, however, there was an obvious omission from the results for the RDX-based system in that there was *no* water consumption. For the TNAZ-based GBU-24 water consumption amounts to almost 2.5 million pounds. The

values in the table and figure include this water consumption. (Geologic and Biotic Resources are raw materials extracted from or grown on the earth or oceans. Intermediate Materials are refined products that have not been traced back to geologic or biotic materials. For example, crude oil is a geologic resource, while gasoline is an intermediate material.)

**Table 4-5. Resource Consumption by Systems (in pounds per GBU-24)**

| Resource | RDX-based GBU-24 | TNAZ-based GBU-24 |
|---|---|---|
| Geologic and Biotic Resources | 20,133 | 6,372,692[(1)] |
| Intermediate Materials | 1,009 | 21,846 |

[(1)] Includes 2.5 million pounds of water consumed

Table 4-6 and Figure 4-6 illustrate the geologic and biotic resource consumption by stage. Figure 4-7 and Table 4-7 present the results for intermediate materials consumption. Again, data for Transportation, Waste Management, and Off-site Electricity Production are identical for the two systems. Differences in resource consumption are not discernable between the systems for any stage except for Precursor Production, where the RDX-based system is considerably lower. The RDX-based system is also lower for Intermediate Materials consumption for both Precursor Production and consumption at Military Facilities.

**Table 4-6. Geologic and Biotic Resource Consumption by Stage (in lb per GBU-24)**

| Stage | RDX-based GBU-24 | TNAZ-based GBU-24 |
|---|---|---|
| Precursor Production | 9,630 | 6,361,792 |
| Military Facilities | 4,178 | 4,575 |
| Transportation | 0 | 0 |
| Waste Management | 100 | 100 |
| Off-site Electricity Generation | 6,225 | 6,225 |

**Table 4-7. Intermediate Materials Consumption by Stage(in lb per GBU-24)**

| Stage | RDX-based GBU-24 | TNAZ-based GBU-24 |
|---|---|---|
| Precursor Production | 296 | 14,268 |
| Military Facilities | 713 | 7,578 |
| Transportation | 0 | 0 |
| Waste Management | 0 | 0 |
| Off-site Electricity Generation | 0 | 0 |

Energy consumption again is lower for the RDX-based GBU-24, by a wide margin (see Figure 10). Energy consumption (all energy sources considered) was 151 million Btus per GBU-24 for the RDX-based system and 1,954 million Btus per GBU-24 for the TNAZ-based system. For the RDX-based system it is 73.4 percent derived from coal and 19.8 percent derived from natural gas, with the balance being electricity or petroleum. Steam (fuel(s) unspecified) was the primary energy source for the TNAZ-based system at 88.4 percent. Nuclear energy (5.2 percent) and coal (3.8 percent) are the next biggest energy sources.

Table 4-8 and Figure 4-9 illustrate Energy consumption by stage. Again the same data were used for both systems for the Transportation, Waste Management, and Off-site Electricity Production stages. For the remaining stages, Precursor Production, and at Military Facilities, the RDX-based system consumes much less energy.

**Table 4-8. Energy Consumption by Stage (in Mbtu per GBU-24)**

| Stage | RDX-based GBU-24 | TNAZ-based GBU-24 |
|---|---|---|
| Precursor Production | 12 | 148 |
| Military Facilities | 61 | 1,728 |
| Transportation | 1 | 1 |
| Waste Management | 3 | 3 |
| Off-site Electricity Production | 73 | 73 |

Table 4-9 presents a summary of all of the comparisons made above. For each comparison, the system that was the most environmentally beneficial, judged as less is better, was indicated on the table with a '•'. A difference between the systems of 15 percent was used to judge which was better, i.e., the value for the TNAZ-based system had to be more than 15 percent higher or lower than the value for the RDX-based system in order for one of the systems to be judged better. If the values for the systems did not differ by more than 15 percent neither was judged to be better. The value of 15 percent was chosen based on the experience of the analyst. As a check on this choice a 10 percent margin was also used. The information in Table 4-9 does not change with a 10 percent margin. If the margin is changed to 20 percent, the outcome of one comparison changes. Instead of the TNAZ-based system being better for Non-Listed Military Facility Emissions, neither system is better.

The value chosen for the margin is a reflection of the perceived data quality. The higher the perceived quality of the data the lower the margin at which one believes comparable systems can be differentiated. Which is the

most correct value? Battelle recently completed a LCI on residential nylon carpet for the U.S. EPA (1997a) in which the propagation of error in an LCI was studied. What was found was that, for the carpet system, individual input parameters could be varied by as much as 20 percent with 95 percent of the output values varying by less than 13 percent. The TNAZ-based system LCI contains a large number of engineering estimates for emissions and consumption simply because the system has not been scaled up and operated at full scale to allow measurements. While these are engineering estimates, they are not likely to vary by more than 20 percent from the true values. Therefore, the output is expected to vary on the order of 15 percent, as it did for the carpet LCI, thus the choice of a 15 percent margin.

**Table 4-9. Life Cycle Inventory Summary Comparison**

| Comparator | RDX-based GBU-24 | TNAZ-based GBU-24 |
|---|---|---|
| Total Emissions | • | |
| Listed Emissions | • | |
| Non-Listed Emissions | | |
| Air Emissions | | |
| Wastewater Emissions | • | |
| Solid Wastes | • | |
| Listed Emissions - Precursor Production | • | |
| Listed Emissions - Military Facilities | • | |
| Listed Emissions - Transportation | | |
| Listed Emissions - Waste Management | | |
| Listed Emissions - Off-site Electricity Production | | |
| Non-Listed Emissions - Precursor Production | | |
| Non-Listed Emissions - Military Facilities | | • |
| Non-Listed Emissions - Transportation | | |
| Non-Listed Emissions - Waste Management | | |
| Non-Listed Emissions - Off-site Electricity Production | | |
| Total Resource Consumption | • | |
| Geologic and Biotic Resources | • | |
| Intermediate Materials | • | |
| Geologic and Biotic Resources - Precursor Production | • | |
| Geologic and Biotic Resources - Military Facilities | | |
| Geologic and Biotic Resources - Transportation | | |
| Geologic and Biotic Resources - Waste Management | | |
| Geologic and Biotic Resources - Off-site Electricity Generation | | |
| Intermediate Materials - Precursor Production | • | |
| Intermediate Materials - Military Facilities | • | |
| Intermediate Materials - Transportation | | |
| Intermediate Materials - Waste Management | | |
| Intermediate Materials - Off-site Electricity Generation | | |
| Total Energy Consumption | • | |
| Energy Consumption - Precursor Production | • | |
| Energy Consumption - Military Facilities | • | |
| Energy Consumption - Transportation | | |
| Energy Consumption - Waste Management | | |
| Energy Consumption - Off-site Electricity Generation | | |

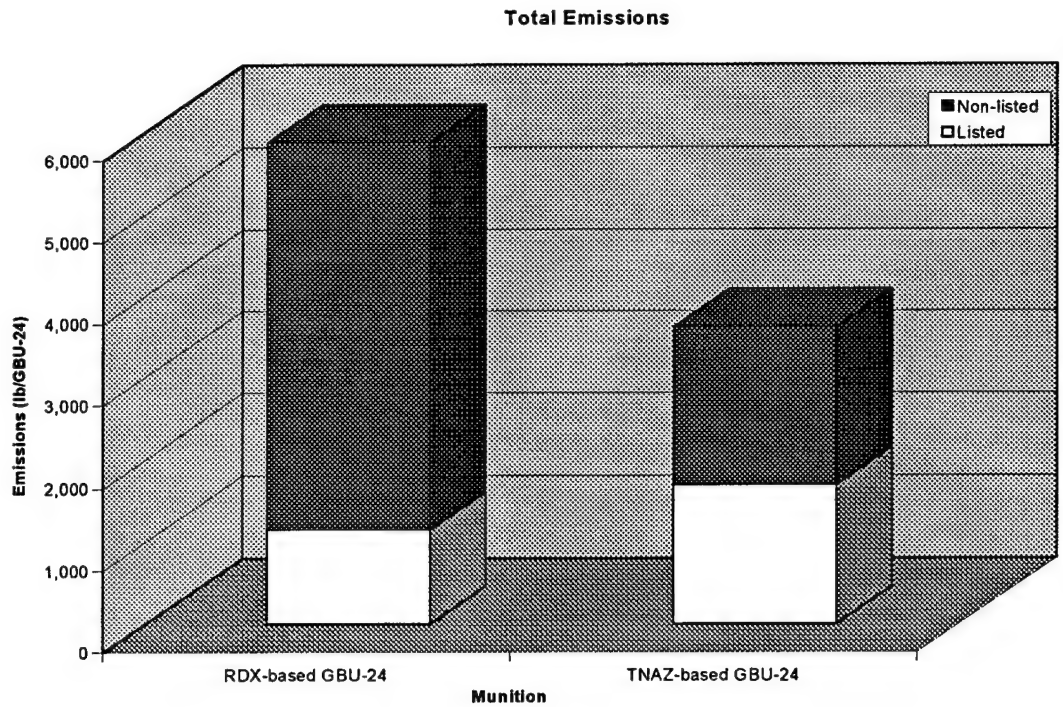


**Figure 4-1. Total emissions.**

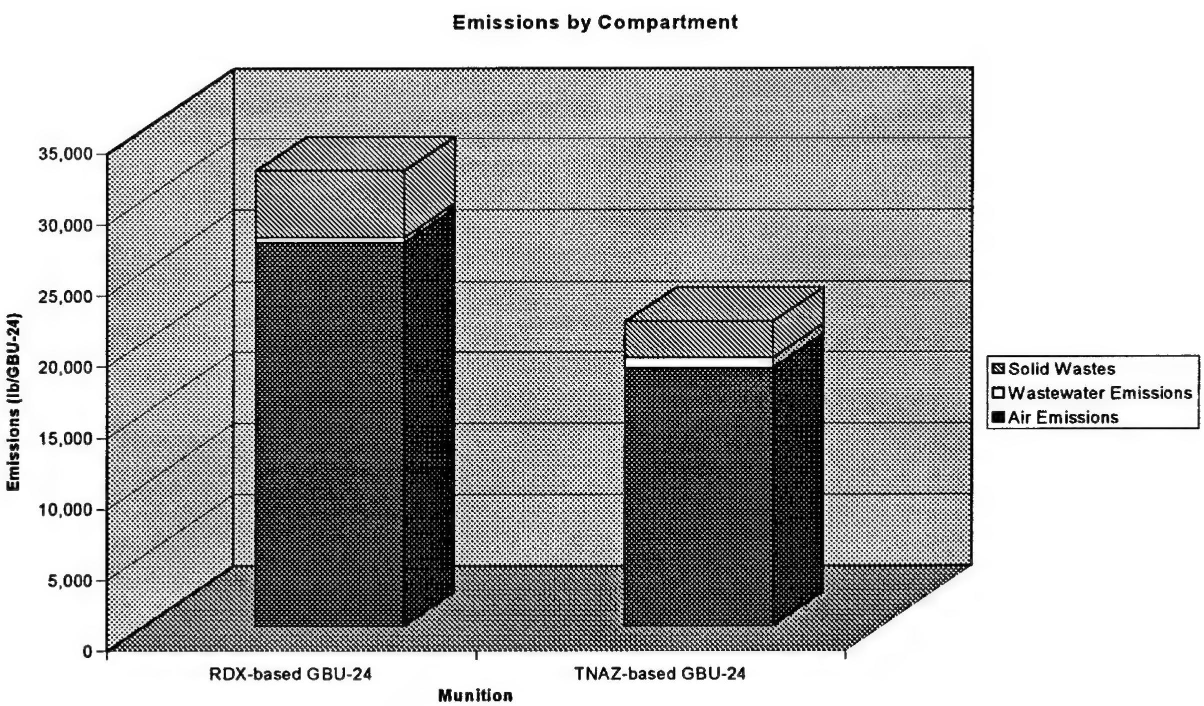


**Figure 4-2. Emissions by compartment.**

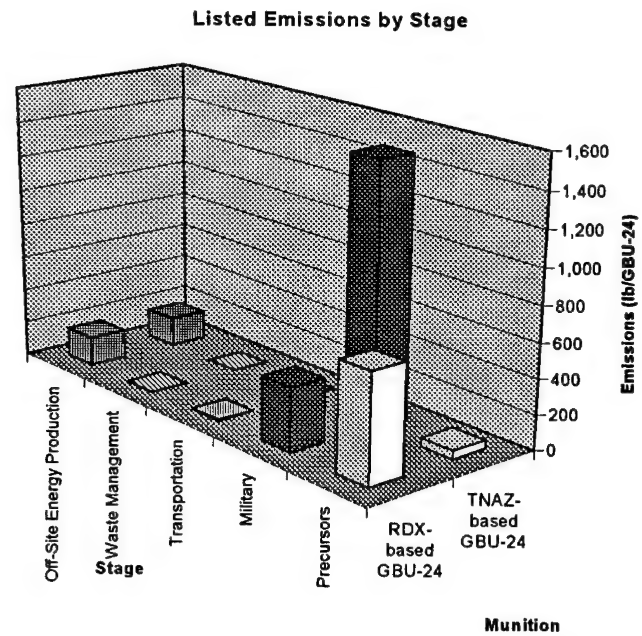


Figure 4-3. Listed emissions by stage.

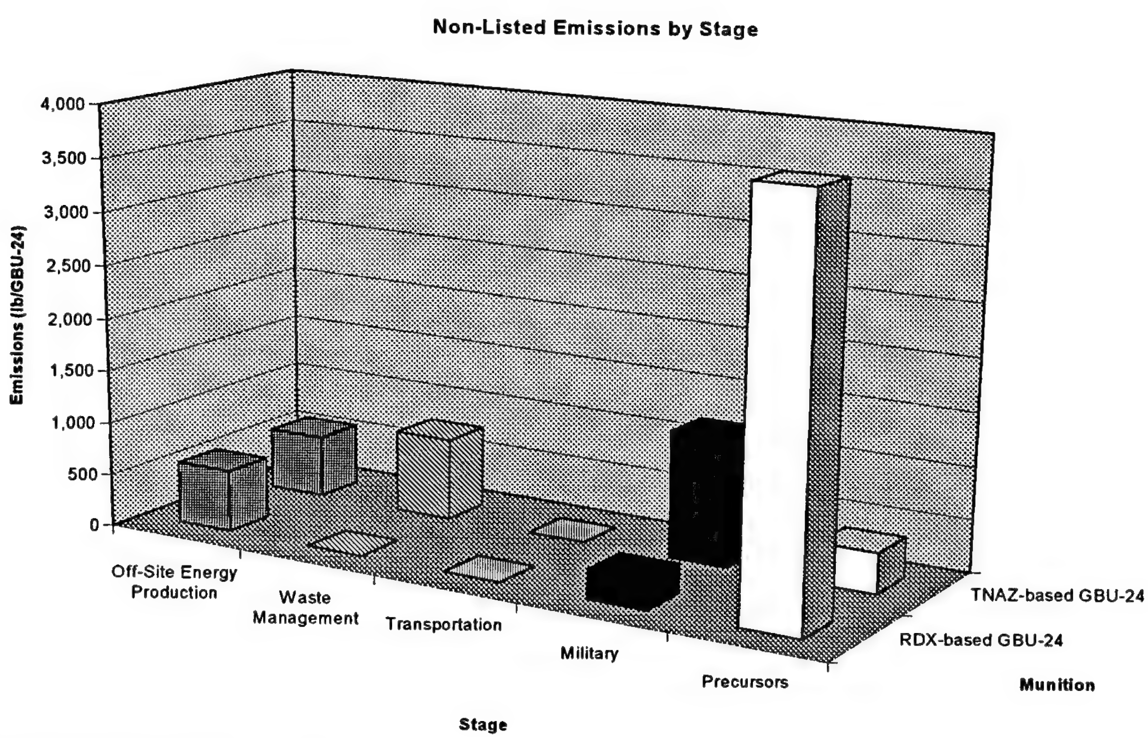


Figure 4-4. Non-Listed emissions by stage.

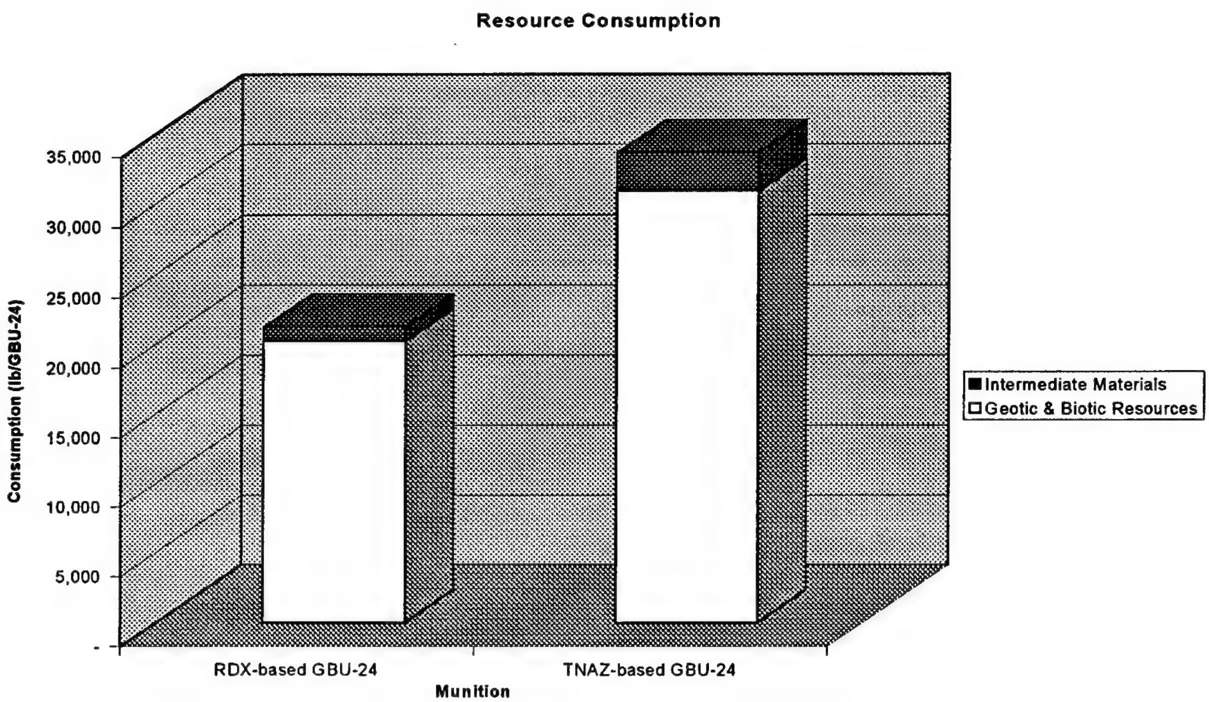


Figure 4-5. Resource consumption.

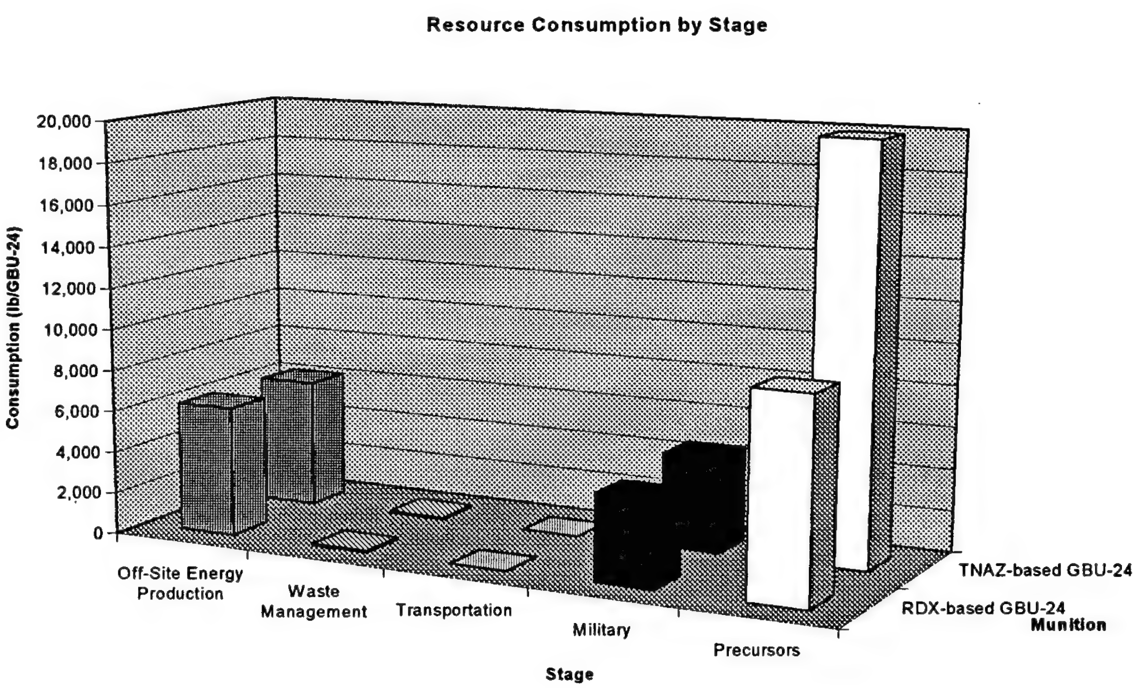


Figure 4-6. Resource consumption by stage.

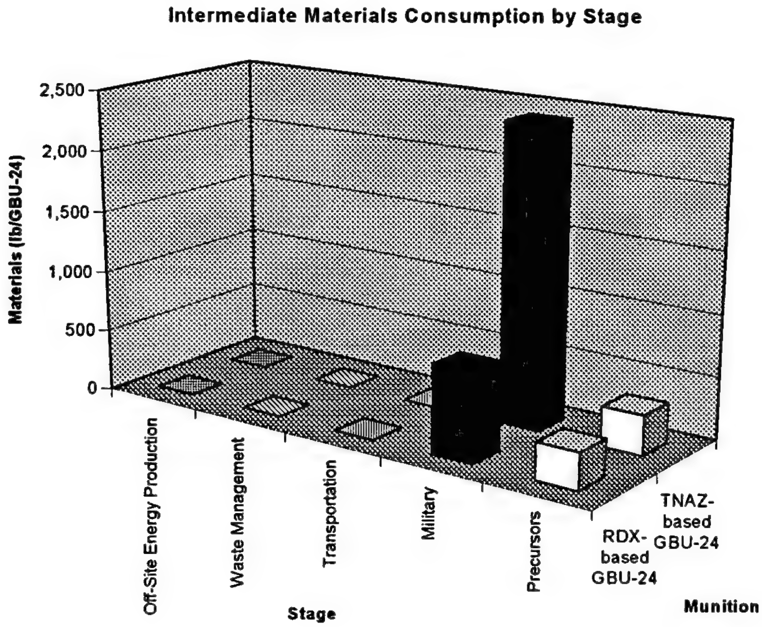


Figure 4-7. Intermediate materials consumption by stage.

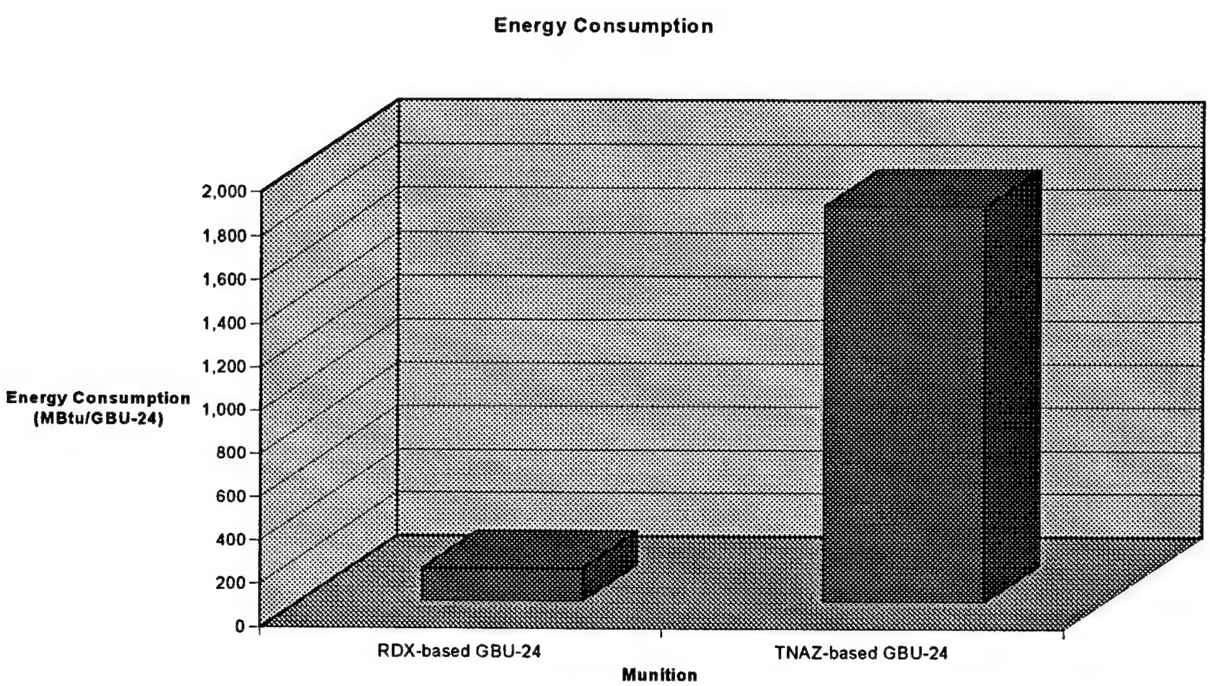


Figure 4-8. Energy consumption.

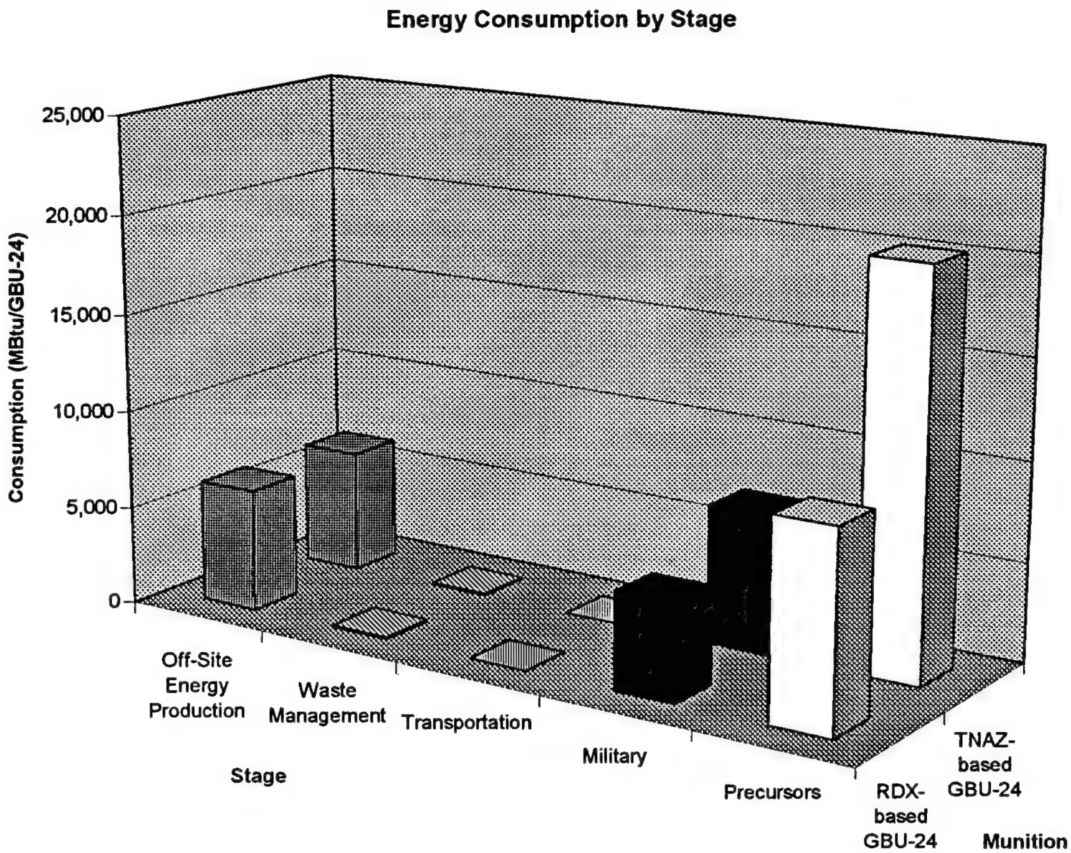


**Figure 4-9. Energy consumption by stage.**

# 5.0 Discussion

The RDX-based GBU-24 is better in 15 of the categories in Table 4-9, the TNAZ-based munition in one. For 19 of the categories there is no clear winner given the data available. By examining Tables 4-1 through 4-8 it can be seen that where the RDX-based munition is better it is generally much better, whereas the TNAZ-based GBU-24 is better by just more than the 15 percent differentiability margin.

Given the relative state of optimization for the systems, it is reasonable to expect the gap between the TNAZ-based and RDX-based systems to narrow for those comparators where the RDX-based system is better. The RDX-based system being a mature technology would not be expected to see significant changes in emissions or consumption. The same may not be said for the TNAZ-based system since much work on optimization of the synthesis reactions is occurring, which will be followed by further optimization achieved through large scale production. This action would be expected to tip the balance away from the RDX-based system being better in so many comparators.

Other unknowns include the true values for Transportation-, Waste Management-, and Off-site Electricity Production-related emissions for the TNAZ-based system. As was discussed above, no data were available on these activities from the LANL modeling efforts so a judgement was made to substitute the equivalent information from the RDX-based system.

These substitutions directly produce ties in 15 of the comparators. Some of these values are probably close to the true value, such as the Transportation-related emissions and consumption where the masses and distances traveled may not change much between the systems. Emissions from Waste Management may actually be lower than modeled for the TNAZ-based system since the TNAZ is recycled; however, Resource and Energy Consumption may increase since the TNAZ is melted out of the bomb casing. Off-site Electricity Production Emissions and Consumption are also expected to decrease since the amount of electricity used for the TNAZ-based system is approximately one-half that used for the RDX-based system. This would have the effect of changing seven of the comparators from a tie to being better under the TNAZ-based system (Total Non-Listed Emissions, Air Emissions, Listed Emissions - Off-site Electricity Production, Non-Listed Emissions - Off-site Electricity Production, Geologic and Biotic Resource Consumption - Off-site Electricity Production, Intermediate Materials Consumption - Off-site Electricity Production, and Energy Consumption - Off-site Electricity Production).

Based upon this qualitative analysis the true picture might look like Table 5-1. The RDX-based munition is better for 18 comparators, the TNAZ-based munition for 10, and which of the two systems is better cannot be determined for seven comparators.

**Table 5-1. Life Cycle Inventory Summary Comparison (after Qualitative Adjustments for Data Quality)**

| Comparator | RDX-based GBU-24 | TNAZ-based GBU-24 |
|---|---|---|
| Total Emissions | • | |
| Listed Emissions | • | |
| Non-Listed Emissions | | • |
| Air Emissions | | • |
| Wastewater Emissions | • | |
| Solid Wastes | • | |
| Listed Emissions - Precursor Production | • | |
| Listed Emissions - Military Facilities | • | |
| Listed Emissions - Transportation | | |
| Listed Emissions - Waste Management | | • |
| Listed Emissions - Off-site Electricity Production | | • |
| Non-Listed Emissions - Precursor Production | | |
| Non-Listed Emissions - Military Facilities | | • |

| Comparator | RDX-based GBU-24 | TNAZ-based GBU-24 |
|---|---|---|
| Non-Listed Emissions - Transportation | | |
| Non-Listed Emissions - Waste Management | | • |
| Non-Listed Emissions - Off-site Electricity Production | | • |
| Total Resource Consumption | • | |
| Geologic and Biotic Resources | • | |
| Intermediate Materials | • | |
| Geologic and Biotic Resources - Precursor Production | • | |
| Geologic and Biotic Resources - Military Facilities | | |
| Geologic and Biotic Resources - Transportation | | |
| Geologic and Biotic Resources - Waste Management | • | |
| Geologic and Biotic Resources - Off-site Electricity Generation | | • |
| Intermediate Materials - Precursor Production | • | |
| Intermediate Materials - Military Facilities | • | |
| Intermediate Materials - Transportation | | |
| Intermediate Materials - Waste Management | • | |
| Intermediate Materials - Off-site Electricity Generation | | • |
| Total Energy Consumption | • | |
| Energy Consumption - Precursor Production | • | |
| Energy Consumption - Military Facilities | • | |
| Energy Consumption - Transportation | | |
| Energy Consumption - Waste Management | • | |
| Energy Consumption - Off-site Electricity Generation | | • |

Two points can be made. First, the RDX-based system appears to be the more environmentally beneficial at this time. Second, the TNAZ-based system does not appear to offer the potential to reduce the amount of Listed wastes emitted during GBU-24 production by the 50 percent goal. In fact, the TNAZ-based system will likely *increase* the amount of listed waste emitted. Currently the TNAZ-based system produces an estimated 18 pounds of Listed waste for every pound of Listed waste produced by the RDX-based system. To meet the goal, the TNAZ-based system would need to see a reduction in Listed wastes emitted of over 97 percent from current estimates.

# 6.0 References


Ali, Mir. 1994. Corn: State-Level Production Costs, Characteristics and Input Use. 1991. USDA/ERS SB-891.

Anderson, I.C. and J.S. Levine. 1987. Simultaneous Field Measurements of Biogenic Emissions of Nitric Oxide. J. Geophys. Res., 92(D1):965-976.

Austin, George. 1984. Shreve's Chemical Process Industries, 5th ed., McGraw-Hill.

Brown, Harry L., Bernard B. Hamel, and BruceA. Hedman. 1985. Energy Analysis of 108 Industrial Processes. Fairmont Press, 314 pp.

Babcock and Wilcox. 1992. Steam: Its Generation and Use, 40th Edition, S.C. Stulz and J.B. Kitto (eds.).

Battaglin, W.A., D.A. Goolsby, and D.K. Mueller. 1994. Relations Between Use, Concentration, and Transport of Agricultural Chemicals in the Mississippi River Basin, in Proceedings of the Annual Summer Symposium of the American Water Resource Association, Effects of Human Induced Changes on Hydrologic Systems, June 26-29, 1994, Jackson Hole, Wyoming.

Baumel, C. Philip, Charles R. Hurburgh, and Tenpao Lee. 1985. Estimates of Total Fuel Consumption in Transporting Grain from Iowa to Major Grain Importing Countries by Alternative Modes and Routes: Special Report 90, Iowa Agricultural and Home Economics Experiment Station, Iowa University of Science and Technology, Ames, Iowa.

Baumel, C. Philip, Stephen Baumhover, Michael A. Lipsman, and Marty J. McVey. 1991. Alternative Investments in the Rural Branch Railroad and County Road Systems, Midwest Transportation Center, Iowa State University, Ames, Iowa.

Bhat, Mahadev G., Burton C. English, Anthony Turhollow, and Herzron Nyangito. 1993. Energy Use in Synthetic Agricultural Inputs: Revisited, Report prepared by the Department of Agricultural Economics and Rural Sociology, The University of Tennessee, Knoxville, for Biofuels Feedstock Development Program Environmental Sciences Division, Oak Ridge National Laboratory, ORNL/Sub/90-99732/2.

Blanchard, Paul H. 1992. Technology of Corn Wet Milling and Associated Processes, Industrial Chemical Library, vol. 4, Elsevier Press, New York.

Blankenhorn, Paul R., et al. 1986. Net Financial and Energy Analyses for Producing Populus Hybrid Under Four Management Strategies: First Rotation, Oak Ridge Nat'l Laboratory, ORNL/Sub/79-07928/1.

Boynton, Robert S. 1980. Chemistry and Technology of Lime and Limestone, Second Edition, John Wiley and Sons, Inc., New York.

Bowman, B.T., et al. 1994. Transport of Herbicides and Nutrients in Surface Runoff from Corn Cropland in Southern Ontario Canadian Journal of Soil Science, 7491):59-66, 1994.

Brown, L. 1995. *Agile Engineering, Strategic Environmental Research and Development Program (SERDP), Task M3.* Tech. Rept. No. HDC-125-95. Holston Army Ammunition Plant, Kingston, TN.

Buhler, D.D., et al. 1993. Water Quality: Atrazine and Alachlor Losses from Subsurface Tile Drainage of a Clay Loam Soil, Journal of Environmental Quality, 22:583-588, 1993

CE Power Systems. 1967. Steam Tables: Properties of Saturated and Superheated Steam, reprinted from ASME Steam Tables (1967).

Cengel, Y. A., and M. Boles. 1989. Thermodynamics: An Engineering Approach, McGraw-Hill, Inc., New York.

Chambers, R.S., et al. 1979. Gasohol: Does It or Doesn't It Produce Positive Net Energy, Science, vol. 206, November 1979, pp. 789-795.

Code of Federal Regulations, 40 CFR 406.15, 1994 edition.

Corn Refiners Association, Inc. 1994?. 1994 Corn Annual, Corn Refiners Association, Washington, D.C.

CRC Press. 1986. Handbook of Physics and Chemistry, $66^{th}$ ed.

DeLuchi, M. 1993. Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity, Argonne National Laboratory, ANL/ESD/TM-22, Vol. 2.

Divine, T.E., D.P. Alzheimer, and W.F. Smith. 1977. Estimates of Process Energy Use in Four Key Food Products Industries, presented at the 1977 Annual Meeting of the Pacific Northwest Region American Society of Agricultural Engineers, Pendelton, OR, September 7-9, 1977.

Eichner, Melissa. 1990. Nitrous Oxide Emissions from Fertilized Soils: Summary of Available Data, J. of Environmental Quality, 19:272-280(1990)

The Fertilizer Institute. 1982. The Fertilizer Handbook.

Giampietro, M., and David Pimentel. 1990. Alcohol and Biogass Production from Biomass, Critical Reviews in Plant Sciences, Vol. 9, No. 3, pp. 213-233.

Glotfelty, D.E., et al. 1984. Atrazine and Simazine Movement to the Wye River Estuary, Journal of Environmental Quality, 13:115-121

Goolsby, D.A., E.M. Thurman, M.L. Pomes, and W.A. Battaglin. 199. Temporal and Geographic Distribution of Herbicides in Precipitation in the Midwest and Northeast United States, 1990-1991, in Proceedings of the Fourth National Conference on Pesticides, New Directions in Pesticide Research, Development and Policy, November 1-3, 1993, Blacksburg, Virginia.

Green, M. 1987. Energy in Pesticide Manufacture, Distribution, and Use, Energy in Plant Nutrition and Pest Control, ed. Z.R. Helsel, New York, Elsevier, pp. 165-196.

Hill, L.D., J.P. Brophy, S. Zhang, and W. Florkowski. 1991. Farmer Attitudes Towards Technological Changes Affecting Grain Handling and Quality, Bulletin 805, University of Illinois at Urbana-Champaign, College of Agriculture, Agricultural Experiment Station.

Hudson, Charles L. 1982. Energy Requirements for Materials Used in Vehicles Characterized for the Tapcut Project, Argonne National Laboratory, ANL/EES-TM-211.

Iowa Agricultural Statistics. 1991. Iowa Crop Report, press release of March 5, 1991, Iowa Agricultural Statistics, Des Moines, Iowa.

Iowa Department of Agriculture and Land Stewardship. 1991. Grain Marketing: Iowa, Iowa Department of Agriculture.

Jones, K.W. 1989. Operation Case Histories of the South Point Ethanol and Kentucky Agricultural Energy Corporation Fuel Ethanol Plants in, Energy from Biomass and Wastes XII, D.L. Klass (ed.), Institute of Gas Technology, pp. 1343-1375.

Kellog, R.L., and S. Wallace. 1995. Erosion Estimates and the Effects of Land Use Changes on Soil Savings Estimates - Insights from the 1992 National Resources Inventory, Poster Board Presented at the 50th Annual Meeting of the Soil and Water Conservation Society, August 6-9, 1995, Des Moines, Iowa.

Kirk, Othmer. 1949. Encyclopedia of Chemical Technology, Wiley Interscience.

Kirk, Othmer. 1964. Encyclopedia of Chemical Technology, $2^{nd}$ ed. Wiley Interscience.

Kirk, Othmer. 1978. Encyclopedia of Chemical Technology, $3^{rd}$ ed. Wiley Interscience.

Kirk, Othmer. 1991. Encyclopedia of Chemical Technology, $4^{th}$ ed. Wiley Interscience.

Lindeburg, M.R. 1988. Engineering Unit Conversions, Professional Publications Inc., Belmont, CA

Lowenheim, F.A. and M.K. Moran. 1975. Faith Keyes and Clarke's Industrial Chemicals. Wiley Interscience.

Marland, G., and A. Turhollow. 1990. Carbon Dioxide Emissions from Production and Combustion of Fuel Ethanol from Corn, Oak Ridge National Laboratory, ORNL/TM-11180.

McGraw Hill. 1984. Perry's Chemical Engineers Handbook, 6th ed.

Mudahar, M.S. and T.P. Hignett. 1981. Energy and Fertilizer: Policy Implications and Options for Developing Countries, Executive Brief, Technical Bulletin IFDC-T-19, International Fertilizer Development Center, Muscle Shoals, Alabama.

Mudahar, M.S. and T.P. Hignett. 1982. Energy and Fertilizer: Policy Implications and Options for Developing Countries, Executive Brief, Technical Bulletin IFDC-T-19, International Fertilizer Development Center, Muscle Shoals, Alabama.

Murray, B.C., D.H. Gross, and T.J. Fox. 1994. Starch Manufacturing: A Profile, Final report to the U.S. EPA by the Center for Economics and Research, Research Triangle Park, NC.

National Corn Growers Association, and National Corn Development Foundation. 1995. The World of Corn: 1995.

Newman, K.E. and R.A. Hardy. 1995. *Data Collection for Life Cycle Assessment Models: Part 1. GBU-24B/B Penetrator Bomb*. IHTR 1784, Indian Head Division, Naval Surface Warfare Center, Indian Head, MD. 17 pp.

Ostic, J.K. 1994. *Life-Cycle Assessment of RDX Products*. Report No. LA-UR-94-4415. Los Alamos National Laboratory, Los Alamos, NM. December, 1994. 7 pp.

Parisi, Frederico. 1983. Energy Balances or Ethanol as a Fuel, Advances in Biochemical Engineering/Biotechnology, 28:42--68 (1983).

Perry, W.J. 1994. "Comprehensive Pollution Prevention Strategy - Memorandum for Secretaries of the Military Departments, et al.," Department of Defense, August 11, 1994.

Pimentel, David (ed.). 1980. Handbook of Energy Utilization in Agriculture, CRC Press, Boca Raton, FL.

Pimentel, David et al. 1988. Food Versus Biomass Fuel: Socioeconomic and Environmental Impacts in the United States, Brazil, India, and Kenya, Advances in Food Research, Vol. 32, pp. 185-238, 1988.

Pimentel, David. 1991. "Ethanol Fuels: Energy Security, Economics, and the Environment", Journal of Agriculture and Environmental Ethics, V.4, pp1-13, 0893-4282, 1991

Shapouri, H, J.A. Duffield, and M.S. Graboski. 1995. Estimating the Net Energy Balance of Corn Ethanol, USDA/ERS, AER-721, Washington, D.C.

SRI. 1993. Directory of Chemical Producers. SRI International, Menlo Park CA.

United States Department of Agriculture, Office of Pesticide Research. 1987. Biologic and Economic Assessment of Stored Corn, Wheat, and Peanut Fumigants in The Biologic and Economic Assessment of Registered Fumigants, USDA Office of Pesticide Research, Washington, D.C.

United States Department of Agriculture. 1993a. Agricultural Resources: Inputs: Situation and Outlook Report, USDA Economic Research Service, AR-32.

United States Department of Agriculture, Economic Research Service. 1993. Feed Situation and Outlook Report.

United States Department of Agriculture, Economic Research Service. 1994a. Agricultural Resource and Environmental Indicators, USDA/ERS, Ag. handbook 705, Washington, D.C.

United States Department of Agriculture, Economic Research Service. 1994b. Sugar and Sweetener: Situation and Outlook Report, SSSV 19N2, June 1994.

United States Department of Agriculture. 1994c (revised 1995). Summary Report: 1992 National Resources Inventory, USDA Natural Resources Conservation Service and the Iowa State University Statistical Laboratory.

United States Department of Agriculture, National Agricultural Statistics Service, Crop Production: 1994 Summary, Cr Pr 2-1(95), January 1995.

United States Department of Agriculture. various. Agricultural Chemical Usage: (yr) Field Crop Summary, USDA National Agricultural Statistics Service, Ag Ch 1(yr).

United States Department of Commerce, Bureau of the Census. 1994. 1992 Census of Manufactures: Grain Mill Products, MC92-I-20D(P).

United States Department of Energy. 1994a. Manufacturing Consumption of Energy 1991. DOE/EIA 0512(91).

United States Department of Energy. 1994b. Emission of Greenhouse gases in the United States 1987-1992. DOE/EIA-0573.

United States Department of Energy. 1994c. Transportation Energy Databook, 11th ed. ORNL-6798

United States Department of Energy. 1995. Annual Energy Review 1993. DOE/EIA-0384(93).

U.S. Department of the Interior, Bureau of Mines. 1994. Mineral Commodity Summaries: 1994

United States Environmental Protection Agency. 1980. Source Category Survey: Starch Manufacturing Industry, EPA-450/3-80-040.

United States Environmental Protection Agency. 1981. Source Category Survey: Animal Feed Dryers, EPA-450/3-81-017

United States Environmental Protection Agency. 1985. Compilation of Air Pollutant Emission Factors 4th ed. AP-42.

United States Environmental Protection Agency. 1991a. Toxics Release Inventory.

United States Environmental Protection Agency. 1991b. Nonroad Engine and Vehicle Emission Study-Report, EPA 460/3-91-02.

United States Environmental Protection Agency. 1991b. Nonroad Engine and Vehicle Emission Study-Appendixes (sp): Draft, 21A-2001 (NTIS #PB92-104462).

United States Environmental Protection Agency. 1993. Life-Cycle Assessment: Inventory Guidelines and Principles. EPA/600/R-92/245.

United States Environmental Protection Agency. 1995. Compilation of Air Pollutant Emission Factors 5th ed. AP-42.

United States Environmental Protection Agency. 1997a. U.S. Residential Nylon Carpet Life-cycle Inventory Demonstration.

United States Environmental Protection Agency. 1997b. A Life-Cycle Impact Assessment Demonstration for the GBU-24.

United States Geological Survey. 1993. Selected Papers on Agricultural Chemicals in Water Resources of the Midcontinental United States, U.S.G.S. Open-File Report 93-418, U.S. G.S. , Denver, CO.

United States International Trade Commission. 1994. Synthetic Organic Chemicals US Production and Sales 1993. US ITC 2810.

Unnasch, Stefan. 1990. Greenhouse Gas Emission from Ethanol Production and Vehicle Use, Acurex Corp. for the Nat'l Corn Growers Association.

Utility Data Institute. 1995. EEI Power Statistics Database.

Watson, R.T. et al. 1990. Greenhouse Gases and Aerosols, in Intergovernmental Panel on Climate Change, Climate Change: The IPCC Scientific Assessment Report Prepared by Working Group I, J.T. Houghton, et al (ed.), UK, 1990.

Weast, R.C., and M.J. Astle (ed). 1981. Handbook of Chemistry and Physics, 62nd Edition, CRC Press, Boca Raton, Florida.

Weinblatt, Herbert, T.S. Reddy, and Anthonly Turhollow. 1982. Energy and Precious Fuels Requirements of Fuel Alcohol Production, Vol. II, Appendices A and B: Ethanol from Grain, DOE/NASA/0292-1.

Whistler, R. L., J.N. BeMiller, and E.F. Paschall (ed.). 1984. Starch: Chemistry and Technology, Academic Press, NY.

# Appendix A

## RDX-based GBU-24 LCI Inventory

GBU-24 Baseline Life Cycle Inventory

Quantities by Site or Life Cycle Stage (in lb/GBU-24 unless noted otherwise)

| Item | RMA & Offsite Material Processing | HSAAP Material Processing | HSAAP Energy Production | MCAAP Material Processing | MCAAP Energy Production | NSWC-IH Demil. | Transport. (All) | Service/ Waste Manage. Offsite | Energy Production Offsite | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| **Listed Wastes** | | | | | | | | | | |
| **Air Emissions** | | | | | | | | | | |
| Acetic acid | 0 | 21 | | | | | | | | 21 |
| Acetone | | 4 | | 0 | | | | | | 4 |
| Aluminum powder | | | | 0 | | | | | | 0 |
| Cyanox dust | | | | 0 | | | | | | 0 |
| Cyclohexanone | | 4 | | | | | | | | 4 |
| Hydrocarbons | 236 | | | | | | 1 | | | 237 |
| Nitric acid | | 0 | | | | | | | | 0 |
| NOx | 96 | 2 | 16 | | 34 | 11 | 3 | | 61 | 223 |
| SOx | 26 | | 44 | | 0 | | | | 108 | 177 |
| Stoddard solvent | | | | 3 | | | | | | 3 |
| **Wastewater Emissions** | | | | | | | | | | |
| Acetic acid | 0 | | | | | | | | | 0 |
| Acetone | | | | 0 | | | | | | 0 |
| Ammonia | 0 | | | | | | | | | 0 |
| Hydroxide | 0 | | | | | | | | | 0 |
| Methanol | | | | | | | | | | 0 |
| Phenol | 0 | | | | | | | | | 0 |
| Sulfuric acid | 4 | | | | | | | | | 4 |
| Trichloroethane | | | | 7 | | 217 | | | | 224 |
| **Solid Wastes** | | | | | | | | | | |
| Aluminum | | | | 0 | | | | | | 0 |
| Aluminum oxide | 255 | | | | | | | | | 255 |
| Pot Liner | 3 | | | | | | | | | 3 |
| RDX | | | | 0 | | | | | | 0 |
| Styrene resin | | | | 3 | | | | | | 3 |
| **Non-Listed Wastes** | | | | | | | | | | |
| **Air Emissions** | | | | | | | | | | |
| Asphaltic particulates | | | | 1 | | | | | | 1 |
| CO | 32 | | 6 | | 5 | 1 | 1 | | 7 | 52 |
| CO2 | 2,490 | 0 | 6,041 | 0 | 1,407 | 209 | 188 | 773 | 15,020 | 26,128 |
| n-Heptane | | | | 0 | | | | | | 0 |
| n-Propyl acetate | | 1 | | | | | | | | 1 |
| Total Particulates | 13 | | 1 | | 0 | | | | 62 | 75 |
| Unspecified | 1 | | 0 | | 16 | | | | 0 | 18 |
| **Wastewater Emissions** | | | | | | | | | | |
| Iron | 1 | | | | | | | | | 1 |
| n-Heptane | | | | 0 | | | | | | 0 |
| Oil | 0 | | | | | | | | | 0 |
| Other Acid | 0 | | | | | | | | | 0 |
| Other Metals | 0 | | | | | | | | | 0 |
| Sulfide | 0 | | | | | | | | | 0 |
| Total Dissolved Solids | 96 | | | | | 12 | | | | 108 |
| Total Suspended Solids | 4 | | | | | 12 | | | | 16 |
| **Solid Wastes** | | | | | | | | | | |
| Aluminum sludge | | 41 | | | | | | | | 41 |
| Ash | 41 | | | | | | | | | 41 |
| Binder | | | | 0 | | | | | | 0 |
| Biosolids | | 55 | | | | | | | | 55 |
| Bottom ash | | | 148 | | | | | | 108 | 256 |
| Catalyst | | | | 0 | | | | | | 0 |
| CXM-7 | | 2 | | 0 | | | | | | 2 |
| FGD Solids | | | | | | | | | 149 | 149 |
| Fly ash | | | 188 | | | | | | 386 | 574 |
| PBXN-109 | | | | 0 | | | | | | 0 |
| Recycle | | | (213) | | | | | | (166) | (379) |
| Red Mud | 155 | | | | | | | | | 155 |
| Slag | | | | | | | | | 41 | 41 |
| Thermosetting compound | | | | 2 | | | | | | 2 |
| Unspecified Solid Waste | 3,499 | | | | | | | | | 3,499 |
| **Resource Consumption** | | | | | | | | | | |
| **Geologic and Biotic Resources** | | | | | | | | | | |
| Bauxite | 390 | | | | | | | | | 390 |
| Coal | 827 | | 2,208 | | | | | | 6,225 | 9,260 |
| Iron ore | 2,243 | | | | | | | | | 2,243 |
| Lime | 5 | | | | | | | | | 5 |
| Natural gas | 2,548 | | | | 1,882 | | | 58 | | 4,489 |
| Nitrogen | 32 | | | | | | | | | 32 |
| Oxygen | 114 | | | | | | | | | 114 |
| Petroleum | 3,454 | | | | 88 | | | 42 | | 3,584 |
| Rock salt | 16 | | | | | | | | | 16 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Intermediate Materials** | | | | | | | | | | |
| Acetic acid | 0 | 108 | | | | | | | | 108 |
| Acetone | | 4 | 0 | 0 | 0 | | | | | 4 |
| Ammonia | 253 | | | | | | | | | 253 |
| Binders | | 48 | | | | | | | | 48 |
| Cyclohexanone | | 4 | | | | | | | | 4 |
| DOA | 43 | | | | | | | | | 43 |
| Formaldehyde | | 181 | | | | | | | | 181 |
| Hexamine | | 137 | | | | | | | | 137 |
| Propyl acetate | | 4 | | | | | | | | 4 |
| Trichloroethane | | | | 224 | | | | | | 224 |
| Triphenyl phosphate | | 3 | | | | | | | | 3 |
| | | | | | | | | | | |
| **Energy Consumption (in MBTU/GBU-24)** | | | | | | | | | | |
| Coal | 12.1 | | 25.9 | | | | | | 73.0 | 111 |
| Electricity | | | 1.7 | | 2.3 | 0.5 | | 1.5 | | 6 |
| Natural Gas | | | | | 28.9 | | | 0.9 | | 30 |
| Petroleum | | | | | 1.9 | | 1.2 | 0.9 | | 4 |

# Appendix B

## TNAZ-Based GBU-24 LCI Life Cycle Inventory

Suggest eliminating rows not in system

GBU-24 Baseline Life Cycle Inventory

Quantities by Site or Life Cycle Stage (in lb/GBU-24 unless noted otherwise) (TNAZ & Solvent Recycle)

| Item | RMA & Offsite Material Processing | HSAAP | | MCAAP | | NSWC-IH Demil. | Transport. (All) | Service/ Waste Manage. Offsite | Energy Production Offsite | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Material Processing | Energy Production | Material Processing | Energy Production | | | | | |
| **Listed Wastes** | | | | | | | | | | |
| **Air Emissions** | | | | | | | | | | |
| Acetaldehyde | 0 | | | | | | | | | 0 |
| Acetic acid | | | | | | | | | | 0 |
| Acetimide | 0 | | | | | | | | | 0 |
| Acetone | | | | 0 | | | | | | 0 |
| Acetonitrile | 0 | | | | | | | | | 0 |
| Acid | 0 | | | | | | | | | 0 |
| Acrolein | 0 | | | | | | | | | 0 |
| Acrylamide | 0 | | | | | | | | | 0 |
| Acrylic acid | 0 | | | | | | | | | 0 |
| Acrylonitrile | 0 | | | | | | | | | 0 |
| Alachlor/Metolachlor | 0 | | | | | | | | | 0 |
| Aldehydes | 0 | | | | | | | | | 0 |
| Aluminum powder | | | | 0 | | | | | | 0 |
| Ammonia | 4 | | | | | | | | | 4 |
| Atrazine | 0 | | | | | | | | | 0 |
| Benzene | 0 | | | | | | | | | 0 |
| Chlorine | 5 | | | | | | | | | 5 |
| Chlorobenzene | 0 | | | | | | | | | 0 |
| Chlorpyrifos | 0 | | | | | | | | | 0 |
| Cyanazine | 0 | | | | | | | | | 0 |
| Cyanox dust | | | | 0 | | | | | | 0 |
| Cyclohexanone | | | | | | | | | | 0 |
| Dichlorobenzene | 0 | | | | | | | | | 0 |
| Fonofos | 0 | | | | | | | | | 0 |
| Hydrazine | 0 | | | | | | | | | 0 |
| Hydrocarbons | 1,256 | | | | | | | | | 1256 |
| Hydrogen chloride | 9 | | | | | | | | | 9 |
| Hydrogen cyanide | 0 | | | | | | | | | 0 |
| Hydrogen sulfide | 0 | | | | | | | | | 0 |
| Isopropanol | 0 | | | | | | | | | 0 |
| Metals | 0 | | | | | | | | | 0 |
| Methane | 0 | | | | | | | | | 0 |
| Nitric acid | 0 | | | | | | 1 | | | 1 |
| NO | 0 | | | | | 3 | | | | 3 |
| N2O | 1 | | | | | | | | | 1 |
| NOx | 22 | | | | 34 | | 3 | | 61 | 121 |
| Organic acids | 0 | | | | | | | | | 0 |
| Phosgene | 0 | | | | | | | | | 0 |
| Producer gas | 280 | | | | | | | | | 280 |
| Propene | 0 | | | | | | | | | 0 |
| Propylene | 0 | | | | | | | | | 0 |
| Pyridine | 0 | | | | | | | | | 0 |
| SOx | 94 | | | | 0 | | | | 108 | 202 |
| Sulfuric acid | 0 | | | | | | | | | 0 |
| Stoddard solvent | | | | 3 | | | | | | 3 |
| Toluene | | 1,982 | | | | | | | | 1982 |
| Terbufos | 0 | | | | | | | | | 0 |
| **Wastewater Emissions** | | | | | | | | | | |
| Acetic acid | | | | | | | | | | 0 |
| Acetone | | | | 0 | | | | | | 0 |
| Alachlor/Metalachlor | 0 | | | | | | | | | 0 |
| Ammonia | 0 | | | | | | | | | 0 |
| Atrazine | 0 | | | | | | | | | 0 |
| Chlorine | 240 | | | | | | | | | 240 |
| Chlorpyrifos | 0 | | | | | | | | | 0 |
| Cyanazine | 0 | | | | | | | | | 0 |
| Fonofos | 0 | | | | | | | | | 0 |
| Hydrazine | 2 | | | | | | | | | 2 |
| Hydroxide | | | | | | | | | | 0 |
| Methanol | | | | | | | | | | 0 |
| Organics | 0 | | | | | | | | | 0 |
| Phenol | 0 | | | | | | | | | 0 |
| Phosgene | 10 | | | | | | | | | 10 |
| ? Pyridine | 2,297 | | | | | | | | | 2297 |
| Pyridine hydrochloride | 3,356 | | | | | | | | | 3356 |
| Sulfuric acid | | | | | | | | | | 0 |
| Terbufos | 0 | | | | | | | | | 0 |
| Trichloroethane | | | | 7 | | | | | | 7 |
| **Solid Wastes** | | | | | | | | | | |
| Acetic acid | | 2,743 | | | | | | | | 2743 |
| Acetaldehyde | 4 | | | | | | | | | 4 |
| Acetamide | 0 | | | | | | | | | 0 |
| Acetonitrile | 0 | 2,864 | | | | | | | | 2864 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Acrolein | 1 | | | | | | | | | 1 |
| Acrylamide | 0 | | | | | | | | | 0 |
| Acrylic acid | 2 | | | | | | | | | 2 |
| Acrylonitrile | 56 | | | | | | | | | 56 |
| Aluminum | | | | 0 | | | | | | 0 |
| Aluminum oxide | | | | | | | | | | 0 |
| Ammonia | 0 | | | | | | | | | 0 |
| BDNA, polymeric | | 122 | | | | | | | | 122 |
| BHMNA.HCL | | 991 | | | | | | | | 991 |
| DIAD.H2 | | 991 | | | | | | | | 991 |
| Hydrogen chloride | 0 | | | | | | | | | 0 |
| Miscellaneous | | 22 | | | | | | | | 22 |
| Organics | | 99 | | | | | | | | 99 |
| Polyamine | | 84 | | | | | | | | 84 |
| Pot Liner | | | | | | | | | | 0 |
| Potassium ferricyanide | | 198 | | | | | | | | 198 |
| 2-Propanol | | 353 | | | | | | | | 353 |
| Pyridine | 0 | | | | | | | | | 0 |
| RDX | | | | 0 | | | | | | 0 |
| Solvent | | 1,029 | | | | | | | | 1029 |
| Styrene resin | | | | 3 | | | | | | 3 |
| TNAZ | | 42 | | | | | | | | 42 |
| Triphenylphosphine | | 1,348 | | | | | | | | 1348 |
| | | | | | | | | | | |
| **Non-Listed Wastes** | | | | | | | | | | |
| **Air Emissions** | | | | | | | | | | |
| Asphaltic particulates | | | | 1 | | | | | | 1 |
| CO | 219 | | | | 5 | 0 | 1 | | 7 | 232 |
| CO2 | 5,038 | | | 0 | 1,407 | 114 | 188 | 773 | 15,020 | 22,541 |
| Fluoride | 0 | | | | | | | | | 0 |
| n-Heptane | | | | 0 | | | | | | 0 |
| Oxygen | | 44 | | | | | | | | 44 |
| PM10 | 15 | | | | | | | | | 15 |
| n-Propyl acetate | | | | | | | | | | 0 |
| Total Particulates | 290 | | | | 0 | | | | 62 | 353 |
| Unspecified | | | | | 16 | | | | 0 | 17 |
| | | | | | | | | | | |
| **Wastewater Emissions** | | | | | | | | | | |
| Ammonium nitrate | | 63 | | | | | | | | 63 |
| BOD | 1 | | | | | | | | | 1 |
| COD | 1 | | | | | | | | | 1 |
| Iron | | | | | | | | | | 0 |
| n-Heptane | | | | 0 | | | | | | 0 |
| Nitrates | 6 | | | | | | | | | 6 |
| Oil | 0 | | | | | | | | | 0 |
| Other Acid | 2 | | | | | | | | | 2 |
| Other Metals | 2 | | | | | | | | | 2 |
| Phosphorus | 0 | | | | | | | | | 0 |
| Potassium | 1 | | | | | | | | | 1 |
| Sodium | 16 | | | | | | | | | 16 |
| Sodium chloride | | 219 | | | | | | | | 219 |
| Sodium formate | | 252 | | | | | | | | 252 |
| Sodium hydroxide | | 0 | | | | | | | | 0 |
| Sodium nitrite | | 672 | | | | | | | | 672 |
| Sodium sulfate | 11 | 2,003 | | | | | | | | 2,014 |
| Sulfide | | | | | | | | | | 0 |
| Total Dissolved Solids | 2 | | | | | | | | | 2 |
| Total Suspended Solids | 13 | | | | | | | | | 13 |
| Water | 11,631,971 | 21,321 | | | | 1,534 | | | | |
| | | | | | | | | | | |
| **Solid Wastes** | | | | | | | | | | |
| Aluminum sludge | | | | | | 48 | | | | 48 |
| Ash | 16 | | | | | 61 | | | | 77 |
| Binder | | | | 0 | | | | | | 0 |
| Biosolids | | | | | | | | | | 0 |
| Bottom ash | | | | | | | | | 108 | 108 |
| Catalyst | | | | 0 | | | | | | 0 |
| CXM-7 TNAZ Expl. Material | | | | 0 | | | | | | 0 |
| Ethanol | | 1,260 | | | | | | | | 1,260 |
| FGD Solids | | | | | | | | | 149 | 149 |
| Formic acid | | 203 | | | | | | | | 203 |
| Fly ash | | | | | | | | | 386 | 386 |
| Molybdenum trioxide | 0 | | | | | | | | | 0 |
| Paraformaldehyde | | 96 | | | | | | | | 96 |
| PBX~~N-109~~ | | | | 0 | | 127 | | | | 128 |
| Propylene | 0 | | | | | | | | | 0 |
| Recycle | | | | | | | | | (166) | (166) |
| Red Mud | | | | | | | | | | 0 |
| Salts | | 84 | | | | | | | | 84 |
| Slag | | | | | | | | | 41 | 41 |
| Thermosetting compound | | | | 2 | | | | | | 2 |
| Unspecified Solid Waste | 656 | | | | | 5 | | | | 661 |
| | | | | | | | | | | |
| **Resource Consumption** | | | | | | | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Geologic and Biotic Resources** | | | | | | | | | | |
| Bauxite | 1 | | | | | | | | | 1 |
| Clay | 0 | | | | | | | | | 0 |
| Coal | 1,363,352 | | | | | | | | 6,225 | 1,369,576 |
| Iron ore | 4 | | | | | | | | | 4 |
| Lime | 149 | | | | | | | | | 149 |
| Natural gas | 2,154,926 | | | | 1,882 | | | 58 | | 2,156,866 |
| Nitrogen | | | | | | | | | | 0 |
| Oxygen | | | | | | | | | | 0 |
| Petroleum | 342,162 | | | | 88 | 6 | | 42 | | 342,298 |
| Phosphate rock | 49 | | | | | | | | | 49 |
| Potassium chloride | 14 | | | | | | | | | 14 |
| Rock salt | 6,335 | | | | | | | | | 6,335 |
| Sand | 0 | | | | | | | | | 0 |
| Soil | 3,769 | | | | | | | | | 3,769 |
| Sulfur | 19 | | | | | | | | | 19 |
| Water | 2,491,013 | 8 | | | | 2,591 | | | | 2,493,612 |
| | | | | | | | | | | |
| **Intermediate Materials** | | | | | | | | | | |
| Acetic acid | 3,164 | | | | | | | | | 3,164 |
| Acetone | | | | 4 | 0 | | | | | 4 |
| Activated carbon | 1 | | | | | 5 | | | | 5 |
| Ammonia | 1 | | | | | | | | | 1 |
| Antifoam Agent | | 0 | | | | | | | | 0 |
| Benzene | 1,399 | | | | | | | | | 1,399 |
| Binders | | | | | | | | | | 0 |
| Chlorine | 2,464 | | | | | | | | | 2,464 |
| CO | 272 | | | | | | | | | 272 |
| Cyclohexanone | | | | | | | | | | 0 |
| DOA | | | | | | | | | | 0 |
| Eth3PO4 | 9 | | | | | | | | | 9 |
| Ethylene glycol | 0 | | | | | | | | | 0 |
| Formaldehyde | | | | | | | | | | 0 |
| Free Base | | 643 | | | | | | | | 643 |
| Freon | 0 | | | | | | | | | 0 |
| Hexamine | | | | | | | | | | 0 |
| Hydrazine | 155 | | | | | | | | | 155 |
| Hydrochloric acid | | 160 | | | | | | | | 160 |
| Hydrogen peroxide | | 165 | | | | | | | | 165 |
| Isopropanol | 582 | | | | | | | | | 582 |
| Nitromethane | | 282 | | | | | | | | 282 |
| Paraformaldehyde | | 630 | | | | | | | | 630 |
| Phosgene | 957 | | | | | | | | | 957 |
| Potassium ferricyanide | | 198 | | | | | | | | 198 |
| 2-Propanol | | 353 | | | | | | | | 353 |
| Propoene | 639 | | | | | | | | | 639 |
| Propyl acetate | | | | | | | | | | 0 |
| Pyridine | 4,594 | | | | | | | | | 4,594 |
| Sodium hydroxide | 24 | | | | | | | | | 24 |
| Sodium nitrite | | 928 | | | | | | | | 928 |
| Sodium persulfate | | 2,003 | | | | | | | | 2,003 |
| Sulfuric acid | 8 | | | | | | | | | 8 |
| Toluene | | 1,982 | | | | | | | | 1,982 |
| Trichloroethane | | | | 224 | | | | | | 224 |
| Triphenyl phosphate | | | | | | | | | | 0 |
| | | | | | | | | | | |
| **Energy Consumption (in MBTU/GBU-24)** | | | | | | | | | | |
| Steam | 33 | | | | | 1,695 | | | | 1,728 |
| Coal | | | | | 2.3 | | | | 73.0 | 75 |
| Electricity | 1.2 | | | | | | | 1.5 | | 3 |
| Hydropotential | 12.5 | | | | | | | | | 12 |
| Natural Gas | | | | | 28.9 | | | 0.9 | | 30 |
| Nuclear Energy | 102.1 | | | | | | | | | 102 |
| Petroleum | | | | | 1.9 | | 1.2 | 0.9 | | 4 |

# Appendix C

## TNAZ-Based GBU-24 Life Cycle Inventory Model

| lb/lb TNAZ | Precursor materials and inputs for TNAZ (Oct 95) | Factored Use lb/lb precursor | Module in LCI |
|---|---|---|---|
| 1.33 | Formaldehyde (37%) | 1 | |
| 1 | Methanol | 1 | |
| 1 | Synthesis gas | 1 | |
| 1.04631263 | Coal | 1.04631263 | |
| 0.596333404 | Oxygen | 0.596333404 | |
| 1.397873673 | water | 1.397873673 | |
| 0.5 | Air (Oxygen) | 0.5 | |
| 3.29 | NIB-Glycerol (50%) | 1 | |
| 0.331156299 | Nitromethane | 0.331156299 | |
| 1 | Petroleum gas | 0.331156299 | |
| 1 | Nitric acid | 0.331156299 | |
| 0.3 | Paraformaldehyde | 0.3 | |
| 0.662171432 | Formaldehyde (37%) | 0.19865143 | |
| 2.33 | di isopropylazodicarboxylate | 1 | |
| 0.667651524 | Azodicarboxyl Chloride | 0.667651524 | |
| 1.80902464 | Phosgene | 1.207798059 | |
| 0.724068226 | Chlorine | 0.874528197 | |
| 0.286032785 | Carbon monoxide | 0.345469842 | |
| 0.0005 | Activated Carbon | 0.000603899 | |
| 0.293090214 | Hydrazine | 0.353993792 | |
| 1.37755102 | Ammonia | 0.487644509 | |
| 3.403061224 | Sodium Hypochlorite | 1.204662547 | |
| 0.238803573 | NaOH | 0.287677721 | |
| 1.058327572 | Chlorine | 1.274927588 | |
| 0.648379344 | Chlorine | 0.432891458 | |
| 0.660415095 | isopropanol | 0.660415095 | |
| 0.725707656 | Propylene | 0.479268291 | |
| 0.008567382 | Sulfuric acid | 0.005658028 | |
| 3.02 | Triphenyl phosphine | 1 | |
| 1.739385713 | Gringard reagent of benzene | 1.739385713 | |
| 0.913761009 | Chlorobenzene | 1.589382845 | |
| 0.685027408 | Benzene | 1.08877081 | |
| 0.629945184 | Chlorine | 1.001224069 | |
| 0.197350102 | Magnesium | 0.343267948 | |
| 0.581718484 | trichlorophosphine | 0.581718484 | |
| 0.237401689 | Phosphorous | 0.138100951 | |
| 0.815298879 | Chlorine | 0.474274428 | |
| 5.57 | Acetic anhydride | 1 | |
| 1.457117595 | Acetic acid | 1.457117595 | |
| 0.485686352 | Methanol | 0.707702129 | |
| 1.04631263 | Coal | 0.740477675 | |
| | Carbon monoxide | 0 | |
| 0.428266893 | Coal | 0 | |
| 0.81 | tert-butylamine | 1 | |
| 1.332284697 | tert-butylchloride | 1.332284697 | |
| 0.673474147 | 2 methyl propylene | 0.8972593 | |
| 0.815171249 | Chlorine | 1.086040181 | |
| 0.245109723 | Ammonia | 0.245109723 | |
| 0.664519692 | Sodium hydroxide | 0.664519692 | |
| 8.8 | Sodium hydroxide (50%) | 1 | |
| 0.59 | rock salt | 0.59 | |
| 1.11 | Hydrochloric acid (37%) | 1 | |
| 1.6 | Hydrogen peroxide (50%) | 1 | |
| 0.056165471 | Hydrogen | 0.056165471 | |
| 0.891481976 | Oxygen | 0.891481976 | |
| 3 | water | 3 | |
| 0.001 | Ethyl anthroquinone Catalyst | 0.001 | |
| 3.6 | Iso propanol | 1 | |
| 0.9 | Propylene | 0.9 | |
| | Crude oil | 0 | |
| 0.0125 | Sulfuric acid | 0.0125 | |
| 2.62 | 2 butanone (MEK) | 1 | |
| 1 | 2 butanol | 1 | |
| 1 | n butene (mix) | 1 | |
| 1.879988255 | Naphtha | 1.879988255 | |
| 1.73292E-05 | ammonia | 1.73292E-05 | |
| 2.27 | Sodium nitrite (s) | 1 | |

| | | | | | |
|---|---|---|---|---|---|
| 0.47 | Potassium ferrocyanide | | | | 1 |
| | 0.474903847 KCN | | | | 0.474903847 |
| | | 0.379525372 HCN | | | 0.180238059 |
| | | 1.046829519 KCl (or KBr) | | | 0.497143365 |
| | 0.196704311 FeCN2 | | | | 0.196704311 |
| | | 0.278354486 HCN | | | 0.132191616 |
| | | 0.575163641 Fe (powder) | | | 0.273147426 |
| | | | | Iron ore | 0 |
| 4.76 | Sodium persulfate | | | | 1 |
| | 1.213756073 Na2SO4 | | | | 1.213756073 |
| 5 | Methyl t-butyl ether (MTBE) | | | | 1 |
| | 0.454373948 Methanol | | | | 0.454373948 |
| | | | 0.8 methane | | 0.363499158 |
| | 0.795628321 Isobutene | | | | 0.795628321 |
| 0.01 | Iron chloride 42o Be | | | | 1 |
| | | Iron metallic | | | 0 |
| | | Hydrochloric acid | | | 0 |
| 0.92 | Nitric acid (70%) | | | | 1 |
| | 0.549672131 Ammonia | | | | 0.549672131 |
| | 10.70491803 Air | | | | 10.70491803 |
| 0.56 | ammonium nitrate (s) | | | | 1 |
| | 0.21243083 Ammonia | | | | 0.21243083 |
| | 0.909292035 Nitric acid | | | | 0.909292035 |
| 2.24 | Ethanol SDA3A | | | | 1 |
| | | Corn, sorghum | | | 0 |
| 6.8 | Acetonitrile | | | | 1 |
| | 0.386722942 Ammonia | | | | 0.386722942 |
| | 0.956630435 Propylene | | | | 0.956630435 |
| 10 | Nitrogen gas | | | | 1 |
| | | Air | | | 0 |
| 100 | Deionized water | | | | 1 |
| | | Sulfuric acid | | | 0 |
| | | Sodium Hydroxide | | | 0 |
| | | Water (natural sweet) | | | 0 |
| 0.01 | Antifoam, DOW 2210 | | | | 1 |

Formaldehyde Production Life Cycle Invnetory

Emissions are in lb/lb unless otherwise specified.

| Item | Quantity | |
|---|---|---|
| **Air** | | |
| NOx | 0.000025 | |
| CO | 0.041807 | |
| SOx | 0.016888 | |
| Formaldehyde | 0.000005 | |
| Methanol | 1.21E-05 | |
| Ammonia | 1.46E-07 | |
| Sulfuric acid | 2.22E-09 | |
| TSP | 0.007691 | |
| CO2 | 0.102758 | |
| Hydrocarbons | 0.031006 | |
| **Water** | | |
| **Solid Wastes** | | |
| Production waste (not innert) | 0.032566 | |
| **Resource Consumption** | | |
| Energy | 2.812753 | kWh/lb |
| Oxygen (from air) | 0.53 | |
| Natural Gas | 0.202 | |
| CO2 | 0.183 | |
| Water | 0.127 | |
| Methanol | 0.47 | |
| Air | 5.76 | |
| Coal | 0.428267 | |

NIB-Glycerol Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

| Item | Quantity |
|---|---|
| **Air Emissions** | |
| 1,2-butylene oxide | 1.9869E-07 |
| 2-nitropropane | 0.00017369 |
| acetaldehyde | 2.0085E-05 |
| acetone | 1.3478E-05 |
| acetonitrile | 6.9212E-06 |
| ammonia | 0.00025343 |
| BrClF2C | 6.292E-07 |
| BrF3C | 2.3678E-06 |
| Chlorine | 1.2915E-06 |
| Cl2F2C | 0.0003146 |
| Formaldehyde | 0.00010352 |
| Hydrogen cyanide | 1.8396E-05 |
| methanol | 7.8202E-06 |
| naphthalene | 0.00018358 |
| nitric acid | 1.573E-06 |
| NOx | 8.3961E-06 |
| CO | 0.00830507 |
| SOx | 0.00335492 |
| Sulfuric acid | 4.4145E-10 |
| TSP | 0.00152788 |
| CO2 | 0.02041303 |
| Hydrocarbons | 0.00615947 |
| **Wastewater Emissions** | |
| ammonia | 4.9673E-07 |
| Hydrogen cyanide | 3.3116E-08 |
| 2-nitropropane | |
| acetaldehyde | 0.00297512 |
| acetone | 0.00159669 |
| acetonitrile | 0.00130257 |
| ammonia | 4.0683E-05 |
| Formaldehyde | 2.2717E-05 |
| Hydrogen cyanide | 1.8876E-06 |
| methanol | 0.00262238 |
| naphthalene | 1.8876E-06 |
| nitric acid | 0.00018373 |
| Wastewater | 23.0110595 |
| **Solid Wastes** | |
| Production waste (not innert) | 0.00646925 |

**Resource Consumption**

| | | |
|---|---|---|
| Steam | 0.00976429 | |
| River Water | 23.0012953 | |
| Electricity | 0.01192499 | kWh |
| Energy | 0.55875742 | kWh |
| Oxygen (from air) | 0.10528526 | |
| Natural Gas | 0.04012759 | |
| CO2 | 0.03635321 | |
| Water | 0.02522873 | |
| Air | 1.14423223 | |
| Coal | 0.08507583 | |

Diisopropylazodicarboxylate Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

| Item | Quantity |
|---|---|
| **Air** | |
| Phosgene | 5.78E-05 |
| Hydrazine | 3.56E-07 |
| Isopropanol | 6.2E-07 |
| Pyridine | 5.59E-06 |
| HCl | 1.59E-05 |
| Cl2 | 1.71E-05 |
| CO | 0.004051 |
| TSP (PM-10) | 0.000383 |
| SOx | 0.002005 |
| NOx | 0.002876 |
| CO2 | 0.849661 |
| Ammonia | 0.001024 |
| Methane | 3.64E-10 |
| Hydrocarbons | 0.006136 |
| Isopropanol | 0.000431 |
| Propene | 1.69E-05 |
| H2S | 4.79E-06 |
| Heavy metals | 4.79E-07 |
| H2SO4 | 3.62E-07 |
| **Wastewater** | |
| Phosgene | 0.009784 |
| Hydrazine | 0.001585 |
| Pyridine | 2.34707 |
| Pyridine HCl | 3.428944 |
| Na2SO4 | 0.011167 |
| COD | 0.000113 |
| BOD | 2.3E-05 |
| Acid as H+ | 0.000995 |
| Metal ions | 0.000354 |
| Cl2 | 0.120565 |
| Dissolved Organics | 9.59E-06 |
| Total Suspended Solids | 0.005836 |
| Crude oil | 4.79E-05 |
| Total Dissolved Solids | 0.000335 |
| Phenol | 3.35E-05 |
| Sodium | 0.008036 |
| **Solid Wastes** | |
| Production waste (not innert) | 0.288446 |

**Resource Consumption**

| | | |
|---|---|---|
| Phosgene | 0.978355 | |
| Hydrazine | 0.158474 | |
| Isopropanol | 0.594389 | |
| Cl2 | 1.220271 | |
| Pyridine | 4.694139 | |
| CO | 0.277794 | |
| Activated Carbon | 0.000604 | |
| Natural Gas | 1.03912 | |
| Electric Power | 0.067589 | kWh |
| Steam | 0.185305 | |
| Heat Energy (fossil fuel) | 0.433116 | kWh |
| Propene | 0.653158 | |
| Sulfuric acid | 0.007711 | |
| NaOH | 0.006289 | |
| Coal | 0.698641 | |
| Hydropower | 2.128203 | |
| Fission | 17.67491 | |
| Iron ore | 0.001774 | |
| Limestone | 0.0511 | |
| Bauxite | 0.000144 | |
| Rock salt | 3.297246 | |
| Clay | 9.59E-06 | |
| Water | 4.615634 | |
| Crude Oil | 0.242245 | |
| Sand | 5.74E-05 | |

Triphenyl phosphine Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

| Item | Quantity | |
|---|---|---|
| **Air** | | |
| Cl2 | 0.003882 | |
| Benzene | 4.92E-06 | |
| HCl | 0.006726 | |
| dichlorobenzenes | 3.98E-06 | |
| chlorobenzene | 6.48E-05 | |
| **Water** | | |
| COD | 0.000233 | |
| BOD | 2.62E-05 | |
| Acid as H+ | 0.000545 | |
| Metal ions | 0.000525 | |
| Cl2 | 0.062069 | |
| Total Suspended Solids | 0.003082 | |
| Crude oil | 0.000109 | |
| Total Dissolved Solids | 0.000662 | |
| Hydrocarbons | 0.000103 | |
| Phenol | 1.09E-06 | |
| Sodium | 0.004131 | |
| **Solid Wastes** | | |
| Production waste (not innert) | 0.156592 | |
| **Resource Consumption** | | |
| Heat Energy (fossil fuel) | 0.880406 | kWh |
| Electric Power | 4.73E-06 | kWh |
| Benzene | 1.102986 | |
| Chlorine | 1.00113 | |
| Sodium hydroxide (dry bassis) | 0.013772 | |
| Natural Gas | 1.159743 | |
| Crude Oil | 0.83093 | |
| Coal | 0.383234 | |
| Hydropower | 1.138573 | |
| Fission | 9.277315 | |
| Iron ore | 0.001122 | |
| Limestone | 0.027564 | |
| Bauxite | 0.00024 | |
| Rock salt | 1.791668 | |
| Clay | 2.18E-05 | |
| Water | 3.733043 | |
| Sand | 2.95E-05 | |

Acetic anhydride Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

| Item | Quantity |
|---|---|
| **Air** | |
| Producer gas | 0.129049 |
| Cinder | 0.110446 |
| Flue gas | 0.494985 |
| TSP | 0.01665 |
| SOx | 0.03655 |
| CO | 0.090473 |
| CO2 | 0.222453 |
| Hydrocarbons | 0.067123 |
| **Wastewater** | |
| Water | 5347.48 |
| **Solid Waste** | |
| Production waste (not innert) | 0.023047 |
| **Resource Consumption** | |
| AcOH | 1.457118 |
| NH3 | 0.000284 |
| Eth3PO4 | 0.004325 |
| Air | 0.251604 |
| Natural Gas | 0.015179 |
| EthGlycol | 2.68E-05 |
| Freon | 2.72E-06 |
| Filtered Water | 6.638878 |
| Steam | 7.593786 |
| River Water | 803.3346 |
| Coal | 0.927121 |

tert-Butylamine Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

| Item | Quantity | |
|---|---|---|
| **Air** | | |
| TSP (PM-10) | 1.45E-10 | |
| SOx | 7.06E-06 | |
| NOx | 1.5E-09 | |
| CO | 0.001936 | |
| CO2 | 0.299867 | |
| Ammonia | 0.000515 | |
| Methane | 1.83E-10 | |
| Hydrocarbons | 0.001157 | |
| **Water** | | |
| COD | 1.75E-05 | |
| BOD | 5.25E-06 | |
| Acid as H+ | 0.000595 | |
| Metal ions | 0.000158 | |
| Cl2 | 0.073524 | |
| Total Suspended Solids | 0.003501 | |
| Total Dissolved Solids | 8.75E-05 | |
| Sodium | 0.004902 | |
| **Solid Wastes** | | |
| Production waste (not innert) | 0.173305 | |
| **Resource Consumption** | | |
| Natural Gas | 0.471558 | |
| Crude Oil | 0.172421 | |
| Coal | 0.407813 | |
| Hydropower | 0.160052 | kWh |
| Fission | 1.337611 | kWh |
| Iron ore | 0.001012 | |
| Limestone | 0.027178 | |
| Rock salt | 1.706175 | |
| Water | 4.499391 | |
| Sand | 3.5E-05 | |
| Electric Power | 0.033972 | kWh |
| Steam | 0.011736 | kWh |

Sodium hydroxide Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

| Item | Quantity | |
|---|---|---|
| **Air** | | |
| **Water** | | |
| COD | 0.00001 | |
| BOD | 0.000003 | |
| Acid as H+ | 0.00034 | |
| Metal ions | 0.00009 | |
| Cl2 | 0.042 | |
| Total Suspended Solids | 0.002 | |
| Total Dissolved solids | 0.00005 | |
| Sodium | 0.0028 | |
| **Solid Wastes** | | |
| Production waste (not innert) | 0.099 | |
| **Resource Consumption** | | |
| Natural Gas | 0.176505 | |
| Crude Oil | 0.129783 | |
| Coal | 0.217294 | |
| Hydropower | 0.09259 | kWh |
| Fission | 0.748543 | kWh |
| Iron ore | 0.00046 | |
| Limestone | 0.0105 | |
| Rock salt | 0.59 | |
| Water | 5.3 | |
| Sand | 0.00002 | |

Isopropanol Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

| Item | Quantity | |
|---|---|---|
| **Air** | | |
| Isopropanol | 0.000652 | |
| Propene | 2.56E-05 | |
| TSP | 0.00072 | |
| SOx | 0.003763 | |
| NOx | 0.0054 | |
| CO | 0.00036 | |
| CO2 | 0.475251 | |
| H2S | 0.000009 | |
| HCl | 0.000009 | |
| Hydrocarbons | 0.007201 | |
| Heavy metals | 9E-07 | |
| H2SO4 | 8E-07 | |
| **Water** | | |
| Na2SO4 | 0.01691 | |
| COD | 0.00018 | |
| BOD | 0.000027 | |
| Acid as H+ | 0.000036 | |
| Metal ions | 0.00018 | |
| Cl2 | 0.000045 | |
| Dissolved Organics | 0.000018 | |
| Total Suspended Solids | 0.00018 | |
| Crude oil | 0.00009 | |
| Total Dissolved Solids | 0.00036 | |
| Phenol | 0.000063 | |
| **Solid Wastes** | | |
| Production waste (not innert) | 0.0081 | |
| **Resource Consumption** | | |
| Heat Energy (fossil fuel) | 0.655825 | |
| Electric Power | 4.68E-06 | |
| Propene | 0.989011 | |
| Natural Gas | 0.462717 | kWh |
| Coal | 0.018379 | kWh |
| Hydropower | 0.013608 | |
| Fission | 0.026082 | |
| Iron ore | 0.00018 | |
| Limestone | 0.00009 | kWh |
| Bauxite | 0.00027 | kWh |

| | |
|---|---|
| Rock salt | 0.0054 |
| Clay | 0.000018 |
| Water | 1.44 |

MEK Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

| Item | Quantity | |
|---|---|---|
| **Air** | | |
| Cl2 | 4.18E-06 | |
| Zinc oxides/Phosphates | 1.136721 | |
| TSP | 0.0008 | |
| SOx | 0.004 | |
| NOx | 0.006 | |
| CO | 0.0004 | |
| CO2 | 0.500021 | |
| H2S | 0.000001 | |
| HCl | 0.00001 | |
| Hydrocarbons | 0.007001 | |
| Heavy metals | 0.000001 | |
| Ammonia | 3.64E-08 | |
| Methane | 1.29E-14 | |
| **Water** | | |
| Dissolved Organics | 3.73E-05 | |
| COD | 0.0002 | |
| BOD | 0.00004 | |
| Acid as H+ | 0.00004 | |
| Metal ions | 0.0003 | |
| Cl2 | 0.00005 | |
| Total Suspended Solids | 0.0002 | |
| Crude oil | 0.0001 | |
| Total dissolved Solids | 0.0004 | |
| Hydrocarbons | 0.00009 | |
| Phenol | 0.000001 | |
| **Solid Wastes** | | |
| P4 production waste (not innert) | 5.85E-07 | |
| Zinc Compounds | 3.8E-05 | |
| Production waste (not innert) | 0.0083 | |
| **Resource Consumption** | | |
| Chlorine | 1.73E-05 | |
| Natural Gas | 0.67741 | |
| Crude Oil | 0.825106 | |
| Coal | 0.017555 | |
| Hydropower | 0.00756 | kWh |
| Fission | 0.02772 | kWh |
| Iron ore | 0.0002 | |

| | | |
|---|---|---|
| Limestone | 0.0001 | |
| Bauxite | 0.0003 | |
| Rock salt | 0.006 | |
| Clay | 0.00002 | |
| Water | 1.6 | |
| Electric Power | 2.4E-06 | kWh |
| Steam | 8.3E-07 | kWh |

MTBE Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

| Item | Quantity | |
|---|---|---|
| **Air** | | |
| MTBE | 7.32E-06 | |
| Methanol | 2.14E-05 | |
| Ammonia | 4.09E-09 | |
| TSP | 0.004131 | |
| SOx | 0.010854 | |
| CO | 0.019308 | |
| CO2 | 0.444505 | |
| Hydrocarbons | 0.019659 | |
| NOx | 0.004774 | |
| H2S | 7.96E-07 | |
| HCl | 7.96E-06 | |
| Heavy metals | 7.96E-07 | |
| **Water** | | |
| MTBE | 3.26E-08 | |
| Methanol | 5.43E-06 | |
| Ammonia | 1.66E-07 | |
| COD | 0.000159 | |
| BOD | 3.18E-05 | |
| Acid as H+ | 3.18E-05 | |
| Metal ions | 0.000239 | |
| Cl2 | 3.98E-05 | |
| Dissolved Organics | 1.59E-05 | |
| Total Suspended Solids | 0.000159 | |
| Crude oil | 7.96E-05 | |
| Total Dissolved Solids | 0.000318 | |
| Hydrocarbosn | 7.16E-05 | |
| Phenol | 7.96E-07 | |
| **Solid Wastes** | | |
| Production waste (not innert) | 0.021401 | |
| **Resource Consumption** | | |
| Electric Power | 1.25E-08 | kWh |
| Isobutylene | 0.844446 | |
| Methanol | 0.273011 | |
| Coal | 0.208561 | |
| Natural Gas | 0.538952 | |
| Crude Oil | 0.656478 | |
| Hydropower | 0.006015 | kWh |

| | | |
|---|---|---|
| Fission | 0.022054 | kWh |
| Iron ore | 0.000159 | |
| Limestone | 7.96E-05 | |
| Bauxite | 0.000239 | |
| Rock salt | 0.004774 | |
| Clay | 1.59E-05 | |
| Water | 1.273005 | |

## Nitric acid Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

| Item | Quantity | |
|---|---|---|
| **Air** | | |
| NOx | 1.04E-05 | |
| TSP (PM-10) | 3.25E-10 | |
| SOx | 1.58E-05 | |
| CO | 0.004342 | |
| CO2 | 0.672469 | |
| Ammonia | 0.001154 | |
| Methane | 4.11E-10 | |
| other organic | 0.002594 | |
| **Wastewater** | | |
| Water | 69.48701 | |
| **Solid Waste** | | |
| **Resource Consumption** | | |
| Steam | 0.029485 | |
| River Water | 69.45752 | |
| Electricity | 0.112193 | kWh |
| Natural Gas | 0.580032 | |
| Steam | 0.026318 | kWh |

Ammonium nitrate Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

| Item | Quantity | |
|---|---|---|
| **Air** | | |
| NOx | 1.37E-05 | |
| **Wastewater** | | |
| Water | 91.78143 | |
| **Solid Waste** | | |
| **Resource Consumption** | | |
| Steam | 0.038946 | kWh |
| River Water | 91.74249 | |
| Electricity | 0.047564 | kWh |

Ethanol Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

| Item | Quantity |
|---|---|
| **Air** | |
| NOx | 0.002435 |
| SOx | 0.001701 |
| PM-10 | 0.011892 |
| Total Particulate | 0.009237 |
| CO | 0.00573 |
| CO2 | 0.547669 |
| Non-Methane Org. Comp. | 0.000729 |
| Methane | 3.09E-06 |
| N2O | 0.000272 |
| HCL | 7.26E-06 |
| Ammonia | 0.000443 |
| Chlorine | 7.95E-07 |
| Sulfuric Acid | 4.9E-07 |
| Hydrocarbons | 0.000343 |
| Aldehydes | 1.67E-05 |
| Organic Acids | 1.32E-06 |
| Fertilizer N20 | 0.000411 |
| Fertilizer NO | 0.000252 |
| Particulate | 0.000139 |
| Nitric Acid | 6.13E-06 |
| Fluoride | 5.58E-07 |
| Acid Mist | 3.14E-05 |
| Herbicides | 0.000157 |
| Alachlor | 3.13E-05 |
| Atrazine | 5.78E-05 |
| Metalachlor | 3.83E-05 |
| Cyanazine | 2.99E-05 |
| Insecticides | 2.49E-05 |
| Fonofos | 4.64E-06 |
| Turbufos | 1.23E-05 |
| Chlorpyrifos | 7.98E-06 |
| **Water** | |
| Total Water Emission | 0.610304 |
| Ammonia | 5.7E-06 |
| Chlorine | 3.26E-08 |
| BOD5 | 0.000407 |
| TSS | 0.000509 |
| Herbicides | 6.11E-06 |
| Alachlor | 2.74E-07 |

| | | |
|---|---|---|
| Atrazine | 2.97E-06 | |
| Metalachlor | 1.2E-06 | |
| Cyanazine | 1.67E-06 | |
| Insecticides | 5.2E-07 | |
| Fonofos | 8E-08 | |
| Turbufos | 2.12E-07 | |
| Chlorpyrifos | 2.28E-07 | |
| Nitrates (as nitrogen) | 0.004885 | |
| Phosphorous | 0.000122 | |
| Potassium | 0.000504 | |
| **Solid Wastes** | | |
| HCL | 1.12E-07 | |
| Ammonia | 1.83E-07 | |
| Coal Ash | 0.012993 | |
| **Resource Consumption** | | |
| Natural gas | 1705.936 | |
| Coal | 1079.272 | |
| Electricity | 0.084213 | kWh |
| Water | 276.1801 | |
| Sulfur | 0.001175 | |
| Diesel | 444.8868 | Btu |
| LPG | 99.77364 | |
| Oil | 58.12006 | |
| Gasoline | 112.5477 | |
| Limestone | 0.039864 | |
| Sulfur | 0.013546 | |
| Water | 275.4681 | |
| Phosphate Rock | 0.038957 | |
| Potassium Chloride | 0.011404 | |
| Soil | 2.991136 | |

Acetonitrile Production Life Cycle Inventory

Emissions are in lb/lb unless otherwise specified.

| Item | Quantity |
|---|---|
| **Air** | |
| Cl2 | 1.33E-06 |
| Acetonitrile | 6.25E-06 |
| Acrolein | 1.22E-07 |
| Acrylic acid | 4.16E-09 |
| Acrylonitrile | 4.5E-05 |
| Ammonia | 0.000824 |
| Hydrogen Cyanide | 6.69E-05 |
| Propylene | 2.3E-05 |
| Acetamide | 1.39E-08 |
| Acetaldehyde | 5.41E-08 |
| Acrylamide | 3.09E-07 |
| Pyridine | 2.11E-07 |
| Hydrocarbons | 0.009633 |
| TSP (PM-10) | 0.000765 |
| SOx | 0.003838 |
| NOx | 0.00574 |
| CO | 0.003438 |
| CO2 | 0.978218 |
| Methane | 2.89E-10 |
| H2S | 9.57E-06 |
| HCl | 9.57E-06 |
| Heavy metals | 9.57E-07 |
| **Water** | |
| Ammonia | 4.02E-07 |
| COD | 0.000191 |
| BOD | 2.87E-05 |
| Acid as H+ | 3.83E-05 |
| Metal ions | 0.000191 |
| Cl2 | 4.78E-05 |
| Dissolved Organics | 1.91E-05 |
| Total Suspended Solids | 0.000191 |
| Crude oil | 9.57E-05 |
| Total Dissolved Solids | 0.000383 |
| Phenol | 6.7E-05 |
| **Solid Wastes** | |
| Acetonitrile | 6.8E-08 |
| Acrylonitrile | 6.94E-09 |
| Acetonitrile | 4.72E-07 |

| | | |
|---|---|---|
| Acrolein | 0.000222 | |
| Acrylic acid | 0.000861 | |
| Acrylonitrile | 0.019429 | |
| Ammonia | 2.91E-05 | |
| Molybdenum Trioxide | 2.64E-05 | |
| Acetamide | 8.32E-06 | |
| Acetaldehyde | 0.001291 | |
| Acrylamide | 0.000112 | |
| Pyridine | 1.53E-08 | |
| LCI component | 0.005274 | |
| Propylene | 7.63E-05 | |
| Molybdenum Trioxide | 0.000124 | |
| Production waste (not innert) | 0.00861 | |

**Resource Consumption**

| | | |
|---|---|---|
| Heat Energy (fossil fuel) | 0.112889 | kWh |
| Electric Power | 0.053599 | kWh |
| Natural Gas | 0.899915 | |
| Steam | 0.018516 | kWh |
| Coal | 0.019536 | |
| Hydropower | 0.014464 | kWh |
| Fission | 0.027723 | kWh |
| Iron ore | 0.000191 | |
| Limestone | 9.57E-05 | |
| Bauxite | 0.000287 | |
| Rock salt | 0.00574 | |
| Clay | 1.91E-05 | |
| Water | 1.530609 | |

Mass Balance on Unit Processes
Brown, Hamel and Hedman

Process No. (- = inflow, + = outflow)

| Material | 1 | 2 | 3 | 4 | 5 | 6 | Total |
|---|---|---|---|---|---|---|---|
| Methanol | -0.54 | | | | 0.07 | | -0.47 |
| Air | -1.55 | | -0.81 | | | -3.4 | -5.76 |
| Steam | -0.05 | -0.5 | | | | 0.55 | 0 |
| Mixture | 2.14 | 0 | 0 | -1.07 | -1.07 | | 0 |
| Loss | | | | | | | 0 |
| Condensate | | 0.5 | | | | -0.5 | 0 |
| Fuel | | | | | | | 0 |
| Stack gas | | | 0.81 | | | 3.4 | 4.21 |
| Cooling water | | | | 0 | | | 0 |
| Off gas | | | | 1.07 | | | 1.07 |
| Formaldehyde | | | | | 1 | | 1 |
| Makeup | | | | | | -0.05 | -0.05 |
| Total | 4.44089E-16 | 0 | 0 | 0 | 0 | 2.64E-16 | 7.08E-16 |

Notes: Inputs and outputs are lb. per lb. of formaldehyde produced.

Energy Balance on Unit Processes
Brown, Hamel and Hedman

Process No. (- = inflow, + = outflow)

| Material | 1 | 2 | 3 | 4 | 5 | 6 | Total |
|---|---|---|---|---|---|---|---|
| Methanol | -4 | | | | 4 | | 0 |
| Air | | | | | | | 0 |
| Steam | -60 | -620 | | | | 680 | 0 |
| Mixture | 58 | 342 | 500 | -840 | -60 | | 0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Loss | 6 | 226.5 | 120 | 90 | 4 | 30.7 | 477.2 |
| Condensate | | 51.5 | | | | -51.5 | 0 |
| Fuel | | | -800 | | | -967 | -1767 |
| Stack gas | | | 180 | | | 307.8 | 487.8 |
| Cooling water | | | | 690 | | | 690 |
| Off gas | | | | 60 | | | 60 |
| Formaldehyde | | | | | 52 | | 52 |
| Makeup | | | | | | | 0 |
| Total | 0 | 0 | 0 | 0 | 0 | 5.68E-14 | 5.68E-14 |

Notes: Inputs and outputs are in BTU per lb. of formaldehyde produced.

| | |
|---|---|
| Sheet Title: | Methanol (for Acetic acid production by Eastman/Malinkrodt at Kingston) |
| Sheet Description: | Engineering calculation (rough)<br>This page calculates the vendor emissions from a plant producing Acetic acid.<br>Not included are raw material production or extraction or water and energy use.<br>(Energy balance is assumed to be close to 0 due to exothermic producer gas synthesis process) |
| References/Citations: | Faith Keyes and Clarke's Industrial Chemicals<br>By F. A. Lowenheim, M. K. Moran<br>Wiley Interscience, 1975<br><br>Perry's Chemical Engineers' Handbook, 6th ed.<br>McGraw Hill, 1984<br><br>AP 42 Ed 4 (1985)<br>US EPA<br><br>Kirk Othmer Encyclopaedia of Chemical Technology<br>2nd ED, 1964 and 4th Ed, 1991-4<br>Wiley Interscience,<br><br>CRC Handbook of Chemistry and Physics, 66th Edition |

Summary Output

Co-product Allocation Calculations

| Co-product | Quantity | Units |
|---|---|---|
| Acetic acid | 1.00E+00 | kg |
| Coal Tar | 1.05E-01 | Kg |
| Total | 1.10515212 | Kg |

Notes: Bbl eq. are calculated on a energy content basis and used to calcualte the allocated LCI emissions factors. Bbl. of CrO production are scaled by multiplying by the ratio of bbl eq. CrO produced to bbl CrO produced.

| LCI components | Unallocated Units | Quantity | Std. Dev. | Allocated Units | Quantity | Std. Dev. | DQI |
|---|---|---|---|---|---|---|---|
| Air | | | | | | | |
| TSP | Kg/Kg Acetic a | 0.0085 | | Kg/Kg Acetic a | 0.007691249 | | 3 |
| SOx | Kg/Kg Acetic a | 0.018658783 | | Kg/Kg Acetic a | 0.016883452 | | 3 |
| CO | Kg/Kg Acetic a | 0.046186813 | | Kg/Kg Acetic a | 0.041792268 | | 3 |
| CO2 | Kg/Kg Acetic a | 0.113563242 | | Kg/Kg Acetic a | 0.102758018 | | 3 |
| total HC's | Kg/Kg Acetic a | 0.034266829 | | Kg/Kg Acetic a | 0.031006436 | | 3 |
| Water | | | | | | | |
| Solid Wastes | | | | | | | |
| Production waste | Kg/Kg Acetic a | 0.035990206 | | | 0.032565839 | | |
| Resource Consumption | | | | | | | |
| Coal | Kg/Kg Acetic a | 0.473300065 | | Kg/Kg Acetic a | 0.428266893 | | |
| Methanol | Kg/Kg Acetic a | 0.536757301 | | Kg/Kg Acetic a | 0.485686352 | | |

Notes: This section is where the project specfic calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors

| Unit from | Unit to | Multiplier | Reference | |
|---|---|---|---|---|
| BTU | J | 1055.056 | CRC, 66th Edition | |
| Wh | J | 3600 | CRC, 66th Edition | |
| bbl CrO | BTU CrO | 5800000 | Chemical Engineers' Handbook, 6th ed. | |
| bbl | gal | 42 | Chemical Engineers' Handbook, 6th ed. | |
| gal diesel | BTU diesel | 118500 | Chemical Engineers' Handbook, 6th ed., Figure 9-4 @ S.G. = .76 and sulfur = 0.5% | |
| gal | L | 3.785412 | CRC, 66th Edition | |
| kg | lb | 2.2046226 | CRC, 66th Edition | |
| yr | day | 365 | | |
| m^3 | bbl (petroleum) | 6.289811 | CRC, 66th Edition | |
| gal CrO | lb CrO | 7.2 | | |
| ton | lb | 2000 | | |
| gal fuel oil | BTU fuel oil | 138000 | | |
| cu. ft NG | BTU NG | 1032 | Chemical Engineers' Handbook, 6th ed. | |
| lb Coal (dry | BTU Coal | 12000 | calculation page B | SD=11% |
| kg NG | MJ NG | 46 | Calculated page C | SD=13% |

Calculations

Acetic acid Production

Energy input
All energy is assumed to come from the heat of combustion in the formation of CO, which is recoverable.

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| Coal | MJ/kg ethylene | 0 | | 3 | kg/kg ethylene | 0 | |
| Oil | MJ/kg ethylene | 0 | 15 | 3 | kg/kg ethylene | 0 | 0.33622909 |
| Natural Gas | MJ/kg ethylene | 0 | | 3 | kg/kg ethylene | 0 | |
| Hydropower | MJ/kg ethylene | 0 | | 3 | | | |
| Fission | MJ/kg ethylene | 0 | | 3 | | | |

Probably different mix in US

Material input
Source: Faith Keyes and Clarke's Industrial Chemicals
By F. A. Lowenheim, M. K. Moran
Wiley Interscience, 1975

Methanol Carbonylation method

| | | | | |
|---|---|---|---|---|
| Stoichiometric ratios: | | | | |
| Methanol net | Kg/Kg Acetic a | 0.533 | | |
| CO net | Kg/Kg Acetic a | 0.467 | | |
| Methanol input | Kg/Kg Acetic a | 0.536757301 | 0.993 | 0.993 conversion of methanol |
| CO input | Kg/Kg Acetic a | 0.513186813 | 0.91 | 0.91 conversion of CO |
| Producer-Gas input | Kg/Kg Acetic a | 1.694973756 | | from Faith Keyes and Clark's Industrial chemicals, 1975 |
| Coal input | Kg/Kg Acetic a | 0.473300065 | | |

| | | | | |
|---|---|---|---|---|
| Emission calculation | (Data from pg D and from AP42 Ed 4 Tbl 1.1-1) | | | |
| Air | | | | |
| CO released from process | Kg/Kg Acetic a | 0.046186813 | 0.09 | unconverted CO |
| Methane | Kg/Kg Acetic a | 0.030509528 | | |
| CO2 | Kg/Kg Acetic a | 0.113563242 | | |
| Particulates | Kg/Kg Acetic a | 0.0085 | 8.5 | g/kg in Cyclone trap outlet (AP42 Ed 4 tbl 1.1-1) |
| Methanol | Kg/Kg Acetic a | 0.003757301 | 0.007 | unconverted assumed to escape in vent stream |
| SOx | Kg/Kg Acetic a | 0.018658783 | 19.5*%S in Co | from AP 42 Ed 4 (1985) tbl 1.1-1<br>Coal assumed to have 1% Sulfur and the coal tar product to have 0.4% sulfur |
| Land | | | | |
| Ash | Kg/Kg Acetic a | 0.035990206 | 0.094 | Ash in coal (assumed recovered) but for air emission |

CO production from Coal through synthesis gas (producer or manufactured)
Source: Page D calculations

Producer gas from Coal (Baddelsey)
25.30% mol CO    30.28% wt CO

Mw CO 28.016
Mw Produc 23.410686

Gas product yield from coal: 3.581182178 lb gas/lb coal

Co-Products:
source: calculated from data on this sheet and on sheet D
Coal tar heating value is median for data of Perry Ed 6 (1984) tbl. 9-12

| | | | | |
|---|---|---|---|---|
| Coal Tar | Kg/Kg Acetic a | 0.10515212 | | |
| Energy equivalent | MJ/Kg Acetic a | 4.153508743 | 39.5 | MJ/Kg coal tar |

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| Oil | | | | | Kg/Kg Acetic acid | | |
| Natural Gas | | | | | Kg/Kg Acetic acid | | |
| Coal | Kg/Kg Acetic a | 0.473300065 | | 3 | Kg/Kg Acetic acid | 0.473300065 | |
| Iron ore | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |
| Methanol | Kg/Kg Acetic a | 0.536757301 | | 3 | Kg/Kg Acetic acid | 0.536757301 | |
| Bauxite | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |
| Rock salt | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |
| Clay | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |

Output

Air

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| TSP | Kg/Kg Acetic a | 0.0085 | | | Kg/Kg Acetic acid | 0.0085 | |
| SOx | Kg/Kg Acetic a | 0.018658783 | | | Kg/Kg Acetic acid | 0.018658783 | |
| NOx | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |
| CO | Kg/Kg Acetic a | 0.046186813 | | | Kg/Kg Acetic acid | 0.046186813 | |
| CO2 | Kg/Kg Acetic a | 0.113563242 | | | Kg/Kg Acetic acid | 0.113563242 | |
| H2S | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |
| HCl | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |
| total HC's | Kg/Kg Acetic a | 0.034266829 | | | Kg/Kg Acetic acid | 0.034266829 | |
| other organic | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |
| Heavy metals | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |

Water

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| COD | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |
| BOD | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |
| Acid as H+ | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |
| Metal ions | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |
| Cl2 | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |
| Dissolved Organics | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |
| suspended solids | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |
| crude oil | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |
| miscelanious dissolved mate | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |
| Phenol | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |

Solid waste

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| Production waste (not innert) | Kg/Kg Acetic a | 0.035990206 | | | Kg/Kg Acetic acid | 0.00128 | |
| Toxic chemicals | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0.000001 | |

Sheet End ======== ============ ========== ========== ========== ========== ============= ========== ========== ======== ======== ========

| Coal type | Moisture | Sulfur | | Heat value | | | | |
|---|---|---|---|---|---|---|---|---|
| | % | % | %dry | Btu/lb | Btu/lbdry | | | |
| Sub bit C | 26 | 0.3 | 0.41 | 8230 | 11121.62 | | | |
| HV bit A | 2.9 | 0.6 | 0.62 | 14170 | 14593.2 | low sulfur coal heating value | | |
| Sub bit B | 22.2 | 0.5 | 0.64 | 9610 | 12352.19 | | | |
| Brown Coa German - R | 55 | 0.3 | 0.67 | 4830 | 10733.33 | | | |
| Sub bit A | 13.9 | 0.6 | 0.70 | 10330 | 11997.68 | SD= | 1295.775 | 0.108169 |
| Meta Anthracite | 9 | 0.7 | 0.77 | 10080 | 11076.92 | Avg= | 11979.16 | |
| LV bit | 2.9 | 0.8 | 0.82 | 14400 | 14830.07 | median | | |
| Anthracite | 4.3 | 0.8 | 0.84 | 12880 | 13458.73 | | 27.86352 | MJ/kg |
| Lignite | 36.8 | 0.9 | 1.42 | 7000 | 11075.95 | | dry base | |
| MV bit | 2.4 | 1.5 | 1.54 | 14490 | 14846.31 | | | |
| Semi anthracite | 2.1 | 1.7 | 1.74 | 13700 | 13993.87 | | | |
| HV bit B | 6.7 | 2.6 | 2.79 | 12390 | 13279.74 | | | |
| HV bit C | 15.4 | 2.9 | 3.43 | 10740 | 12695.04 | | | |

bit=Bituminous
V=Volatility
L=low
M=Medium
H=high

Source: Kirk Othmer vol 4 1949

| mol% | Mwt | heat value MJ/M^3 | Rio Arriba, | Terrell, Tex | Stanton, Ka | San Juan, N | Olds Field, | Cliffside, Texas | avg | SD (rel) |
|---|---|---|---|---|---|---|---|---|---|---|
| Methane | 16.043 | 37.57 | 96.91 | 45.64 | 67.56 | 77.28 | 52.34 | 65.8 | | |
| ethane | 30.07 | 65.83 | 1.33 | 0.21 | 6.23 | 11.18 | 0.41 | 3.8 | | |
| propane | 44.097 | 93.6 | 0.19 | | 3.18 | 5.83 | 0.14 | 1.7 | | |
| butane | 58.123 | 120.98 | 0.05 | | 1.42 | 2.34 | 0.16 | 0.8 | | |
| pentane+ | 72.15 | 148.84 | 0.02 | | 0.04 | 1.18 | 0.41 | 0.5 | | |
| CO2 | 44.01 | 0 | 0.82 | 53.93 | 0.07 | 0.8 | 8.22 | | | |
| H2S | 34.076 | 23.7 | | 0.01 | | | 35.79 | | | |
| N2 | 28.013 | 0 | 0.68 | 0.21 | 21.14 | 1.39 | 2.53 | 25.6 | avg | SD (rel) |
| Mol wt: | | | 16.62585 | 31.182 | 20.92126 | 21.28362 | 25.49289 | 20.44567 | 19.61024 | 10.79% |
| heating valu | MJ/M^3 | | 37.6 | 17.3 | 34.9 | 46.8 | 30 | 30.7 | 39.76667 | 12.81% |
| | MJ/KG | | 50.65847 | 12.42768 | 37.36678 | 49.25478 | 26.36029 | 33.63451 | 45.76001 | 13.03% |
| | 0.0224M^3/mol | | | too high CO2 content for use | | | too high Sulfur content | too low heating value(?) | | |

Source: Kirk Othmer Ed 4 vol 12 1993

MJ/m^3

Heating values for processed city natural gas:
source Perry 6 (1984)
averaged from table 9-14

Btu/scf 1049.571

Synopsis of table 9-14

| mol% | Mwt | heat value MJ/M^3 | Baltimore Md | Columbus Ohio | Houston Tx | Burmingham Al | Washington DC | Phoenix Az | avg | SD (rel) |
|---|---|---|---|---|---|---|---|---|---|---|
| Methane | 16.043 | 37.57 | 94.4 | 93.14 | 92.5 | 93.14 | 95.15 | 87.37 | | |
| ethane | 30.07 | 65.83 | 3.4 | 3.58 | 4.8 | 2.5 | 2.84 | 8.11 | | |
| propane | 44.097 | 93.6 | 0.6 | 0.66 | 2 | 0.67 | 0.63 | 2.26 | | |
| butane | 58.123 | 120.98 | 0.5 | 0.22 | 0.3 | 0.32 | 0.24 | 0.13 | | |
| pentane+ | 72.15 | 148.84 | 0 | 0.09 | 0 | 0.12 | 0.05 | 0 | | |
| CO2 | 44.01 | 0 | 0.6 | 0.85 | 0.27 | 1.06 | 0.62 | 0.61 | | |
| H2S | 34.076 | 23.7 | | 0.01 | | | | | | |
| N2 | 28.013 | 0 | 0.5 | 0.21 | 21.14 | 2.14 | 0.42 | 1.37 | avg | SD (rel) |
| Mol wt: | | | 17.12629 | 16.93912 | 23.38022 | 17.32821 | 16.9628 | 18.17984 | 18.31941 | 15.84% |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| heating valu | MJ/M^3 | 39.2023 | 38.3444 | 38.4563 | 38.1952 | 38.8666 | 39.9483 | | 38.83552 | 1.10% |
| | MJ/KG | 51.27388 | 50.70597 | 36.84401 | 49.37455 | 51.32477 | 49.22167 | | 48.12414 | 13.30% |

0.0224M^3/mol

Manufactured gas

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Data from KO 2 (1964) for "modern mechanical method" | | | | Gas | | | gas heat value | | | | Tar data | |
| | Moisture | Heating valueBtu/lb | | Gas yield scf/ton | | gas lb/lb co | Gross heat value Btu/s | | Btu/ton coa | Btu/lb coal | Tar yield gal/ton | |
| | | wet | dry | wet base | dry base | | wet base | dry base | wet base | wet base | wet base | dry base |
| Anthracite | 0.051 | 10800 | 11380.4 | 123900 | 130558.5 | | 138 | 145.4162 | 17098200 | 8549.1 | 9.5 | 10.01054 |
| Belgian Co | 0.026 | 11980 | 12299.79 | 120900 | 124127.3 | | 150 | 154.0041 | 18135000 | 9067.5 | 1 | 1.026694 |
| Baddesley | 0.05 | 12080 | 12715.79 | 116100 | 122210.5 | 3.581182 | 165.6 | 174.3158 | 19226160 | 9613.08 | 21 | 22.10526 |

On the basis of 10% tar production in the process the Baddesley type coal is used

This coal then provides 9613.08 gas heating value in Btu/lb coal

| | | | | | | |
|---|---|---|---|---|---|---|
| Baddesley coal ga | | | | | | |
| compositiorMWt | | vol% | O2 per mol | mol O2 per mol gas | | |
| CO2 | 44.01 | 6.7 | 0 | 0 | | |
| alkyls | | | | | | |
| O2 | 31.9988 | 0 | 0 | 0 | | |
| CO | 28.016 | 25.3 | 0.5 | 0.1265 | | |
| H2 | 2.0158 | 21 | 0.5 | 0.105 | | |
| CH4 | 16.043 | 1.8 | 2 | 0.036 | | |
| N2 | 28.013 | 45.2 | 0 | 0 | 0.578864 | mol air producing mol gas |
| Gas Mwt | 23.41069 | | | 0.2675 mol O2 per mol gas | 1.277093 | mol air to burn mol gas |
| | | | | 0.365631 kg O2 per Kg gas | 1.855957 | mol air used/mol gas |
| ideal gas density of producer gas | | | | 1.580041 kgair/kg gas | 2.296221 | kg air used / kg gas |
| 0.9882 kg/m^3 | | | | | | |
| 0.061691 lb/s cuf | | | | d=Mw/0.0224 | | |

| | | | | | |
|---|---|---|---|---|---|
| physical data | | | | | |
| Density of T | 75 | lb/cuf | | | Perry 6 (1984) |
| | 1200 | kg/m^3 | | | |
| | 10.01449 | lb/gal | | | |
| Units | | | | | |
| scf is volume in cubic feet at 60 Farenheit and 30" Hg | | | | | KO 2 (1964) |
| | | 288.7056 | 42.2115 | 0.02369 | |
| density | lb/cuf | lb/gal | kg/m^3 | | Perry 6 (1984) |
| | 0.062428 | 0.008345 | 1 | | |
| | 7.480519 | 1 | 119.8264 | | |
| | 1 | 0.133681 | 16.01846 | | |
| mass | ton (short - | lb | kg | | Perry 6 (1984) |
| | 1 | 2000 | | | |
| | | 2.204623 | 1 | | |
| Pressure | "Hg | N/m^2 | atm | psia | Perry 6 (1984) |
| | 1 | 3376.9 | 0.033327 | 0.489775 | |
| | 2.041754 | 6894.8 | 0.068046 | 1 | |
| | 30.00533 | 101325 | 1 | 14.69586 | |
| | | 1 | | | |
| Heat value | MJ/m^3 | btu/scf | | | Perry 6 (1984) |
| | 0.0373 | 1 | | | |
| Energy | MJ | Btu | | | Perry 6 (1984) for steam table values |
| | 0.001055 | 1 | | | |

| | | | | |
|---|---|---|---|---|
| | molar | | | kg air per kg |
| dry air composition | | Mwt | mass comp | component |
| N2 | 0.78084 | 28.0134 | 0.75521 | 1.324134 |
| O2 | 0.20946 | 31.9988 | 0.231406 | 4.321406 |
| CO2 | 0.00033 | 44.01 | 0.000501 | 1994.319 |
| Ar | 0.00934 | 39.948 | 0.012882 | 77.62792 |
| total | 0.99997 | 28.96409 | 1 | |

| | |
|---|---|
| Sheet Title: | Nitroethane/nitromethane |
| Sheet Description: | Nitroethane/nitromethane |
| | Nitroethane is produced as a co-product in the production of nitorethane, nitromethane, 1-nitropropane, and 2-nitropropane |
| References/Citations: | TRI inventory for 1991 for W. R. Grace Deer Park, Tx Facility |
| | Personal communication from the plant manager of the Deer Park Facility to John Becker, Sept 6, 1995, indicating plant capacity for nitroparaffins at 20,000,000 lb/yr while operating. Plant closed in 1992. |
| | Kirk-Othmer Enclyclopedia of Chemical Technology. 3rd ed. 1978. v15. "Nitroparaffins |

Summary Output:

| Allocated LCI component | | Units | Quantity | DQI |
|---|---|---|---|---|
| air emissions | | | | |
| | 1,2-butylene | lb/lb | 0.0000006 | 2 |
| | 2-nitropropar | lb/lb | 0.0005245 | 2 |
| | acetaldehyde | lb/lb | 6.065E-05 | 2 |
| | acetone | lb/lb | 0.0000407 | 2 |
| | acetonitrile | lb/lb | 0.0000209 | 2 |
| | ammonia | lb/lb | 0.0007652 | 2 |
| | BrClF2C | lb/lb | 0.0000019 | 2 |
| | BrF3C | lb/lb | 7.15E-06 | 2 |
| | Chlorine | lb/lb | 0.0000039 | 2 |
| | Cl2F2C | lb/lb | 0.00095 | 2 |
| | Formaldehyd | lb/lb | 0.0003096 | 2 |
| | Hydrogen cy | lb/lb | 5.555E-05 | 2 |
| | methanol | lb/lb | 1.635E-05 | 2 |
| | naphthalene | lb/lb | 0.0005544 | 2 |
| | nitric acid | lb/lb | 4.75E-06 | 2 |
| water | | | | |
| | ammonia | lb/lb | 0.0000015 | 2 |
| | Hydrogen cy | lb/lb | 0.0000001 | 2 |
| underground | | | | |
| | 2-nitropropar | lb/lb | 0.0069671 | 2 |
| | acetaldehyde | lb/lb | 0.0089841 | 2 |
| | acetone | lb/lb | 0.0048216 | 2 |
| | acetonitrile | lb/lb | 0.0039334 | 2 |
| | ammonia | lb/lb | 0.0001229 | 2 |
| | Formaldehyd | lb/lb | 0.0000686 | 2 |
| | Hydrogen cy | lb/lb | 0.0000057 | 2 |
| | methanol | lb/lb | 0.0079189 | 2 |
| | naphthalene | lb/lb | 0.0000057 | 2 |
| | nitric acid | lb/lb | 0.0005548 | 2 |

Notes: The 4 co-products are produced as part of the same reaction.
Product percentage varies with operating conditions (Kirk-Othmer), but emissions must be considered on a lb/lb basis as 4 equal co-products.

Conversion Factors

| Unit from | Unit to | Multiplier |
|---|---|---|

Calculations

Table Title

Table Reference/Citation

| LCI component | | Raw/ Input Units | Raw/ Input Quan. | Raw/ put Std. Dev | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|---|
| air emissions | | | | | | | | |
| | 1,2-butylene | lb/yr | 12 | | 4 | lb/lb | 0.0000006 | |
| | 2-nitropropan | lb/yr | 10490 | | 4 | lb/lb | 0.0005245 | |
| | acetaldehyde | lb/yr | 1213 | | 4 | lb/lb | 6.065E-05 | |
| | acetone | lb/yr | 814 | | 4 | lb/lb | 0.0000407 | |
| | acetonitrile | lb/yr | 418 | | 4 | lb/lb | 0.0000209 | |
| | ammonia | lb/yr | 15304 | | 4 | lb/lb | 0.0007652 | |
| | BrClF2C | lb/yr | 38 | | 4 | lb/lb | 0.0000019 | |
| | BrF3C | lb/yr | 143 | | 4 | lb/lb | 7.15E-06 | |
| | Chlorine | lb/yr | 78 | | 4 | lb/lb | 0.0000039 | |
| | Cl2F2C | lb/yr | 19000 | | 4 | lb/lb | 0.00095 | |
| | Formaldehyd | lb/yr | 6192 | | 4 | lb/lb | 0.0003096 | |
| | Hydrogen cy | lb/yr | 1111 | | 4 | lb/lb | 5.555E-05 | |
| | methanol | lb/yr | 327 | | 4 | lb/lb | 1.635E-05 | |
| | naphthalene | lb/yr | 11087 | | 4 | lb/lb | 0.0005544 | |
| | nitric acid | lb/yr | 95 | | 4 | lb/lb | 4.75E-06 | |
| water | | | | | | | | |
| | ammonia | lb/yr | 30 | | 4 | lb/lb | 0.0000015 | |
| | Hydrogen cy | lb/yr | 2 | | 4 | lb/lb | 0.0000001 | |
| underground | | | | | | | | |
| | 2-nitropropan | lb/yr | 139342 | | 4 | lb/lb | 0.0069671 | |
| | acetaldehyde | lb/yr | 179681 | | 4 | lb/lb | 0.0089841 | |
| | acetone | lb/yr | 96431 | | 4 | lb/lb | 0.0048216 | |
| | acetonitrile | lb/yr | 78668 | | 4 | lb/lb | 0.0039334 | |
| | ammonia | lb/yr | 2457 | | 4 | lb/lb | 0.0001229 | |
| | Formaldehyd | lb/yr | 1372 | | 4 | lb/lb | 0.0000686 | |
| | Hydrogen cy | lb/yr | 114 | | 4 | lb/lb | 0.0000057 | |
| | methanol | lb/yr | 158377 | | 4 | lb/lb | 0.0079189 | |
| | naphthalene | lb/yr | 114 | | 4 | lb/lb | 0.0000057 | |
| | nitric acid | lb/yr | 11096 | | 4 | lb/lb | 0.0005548 | |

Notes: Based ont eh information supplied by the plant manager of a production capacity of 20,000,000 lb/yr.

Sheet End ========= ========= ========= ========= ========= ========= ========= ========= =========

Nitric Acid+ Ammonium Nitrate
Source: all data

Technical report HDC-125-95 Pg 14
By Laurie J. Brown
Holston Defense Corporation
Subsidiary of Eastman Chemical Co.
Kingsport, TN 37660

| | | | Conc. | Raw data in lb | kg per kg solution | kg per kg HNO3 | kg per kg NH4NO3 |
|---|---|---|---|---|---|---|---|
| Product | | | | | | | |
| | | Solution | | 1.356 | 1 | 1.7730496 | 2.3419204 |
| | | HNO3 | 0.564 | | 0.564 | 1 | 1.3208431 |
| | | NH4NO3 | 0.427 | | 0.427 | 0.7570922 | 1 |
| | | W | 0.009 | | 0.009 | 0.0159574 | 0.0210773 |
| Inputs | | | | | | | |
| | Materials | | | | | | |
| | | HNO3 | 0.99 | 1.233 | 0.909292 | 1.6122199 | 2.1294895 |
| | | NH3 | | 0.123 | 0.090708 | 0.1608297 | 0.2124308 |
| | | Steam | | 0.02255 | 0.0166298 | 0.0294854 | 0.0389457 |
| | | River Water | | 53.12 | 39.174041 | 69.45752 | 91.742485 |
| | Energy | | | | | | |
| | | Electricity | kWhr | 0.02754 | 0.0203097 | 0.0360102 | 0.0475638 |
| Waste | | | | | | | |
| | Water return to river (Non-contact) | | | 53.12 | 39.174041 | 69.45752 | 91.742485 |
| | Steam Condensate to river (Non-contact) | | | 0.02255 | 0.0166298 | 0.0294854 | 0.0389457 |
| Air Emiossion | | | | | | | |
| | | NOx (value is for NO2) | | 7.921E-06 | 5.841E-06 | 1.036E-05 | 1.368E-05 |

Nitric Acid concentration
Source: all data

Technical report HDC-125-95 Pg 12
By Laurie J. Brown
Holston Defense Corporation
Subsidiary of Eastman Chemical Co.
Kingsport, TN 37660

| | | | Conc. wt frac. | Raw data in lb | kg per kg solution | kg per kg HNO3 |
|---|---|---|---|---|---|---|
| Product | | | | | | |
| | | Solution | | 1.233 | 1 | 1.2454545 |
| | | HNO3 | 0.99 | | 0.99 | 1 |
| | | W | 0.01 | | 0.01 | 0.010101 |
| Output | | | | | | |
| | to IWTF | water | | 0.8595 | 0.6970803 | 0.8681818 |
| | | NaNO3/w | 0.904 | 0.01295 | 0.0105028 | 0.0130808 |
| | | NaNO3 | as pure | 0.0117068 | 0.0094946 | 0.0118251 |
| | | water | as pure | 0.8607432 | 0.6980886 | 0.8694376 |
| | | Mg(NO3)2/w | 0.6 | 0.009053 | 0.0073423 | 0.0091444 |
| Inputs | | | | | | |
| | Materials | | | | | |
| | | HNO3 | 0.61 | 2.031 | 1.6472019 | 2.0515152 |
| | | Na2CO3 | | 0.007304 | 0.0059238 | 0.0073778 |
| | | City Water | | 0.08226 | 0.0667153 | 0.0830909 |
| | | MgO | | 0.001478 | 0.0011987 | 0.0014929 |
| | | Steam | | 2.9 | 2.351987 | 2.9292929 |
| | | River Water | | 28.81 | 23.365775 | 29.10101 |
| | Energy | | | | | |
| | | Electricity | kWhr | 0.05507 | 0.0446634 | 0.0556263 |
| Waste | | | | | | |
| | Water return to river (Non-contact) | | | 28.81 | 23.365775 | 29.10101 |
| | Steam Condensate to river (Non-contact) | | | 2.9 | 2.351987 | 2.9292929 |
| Air Emiossion | | | | | | |
| | | NOx (value is for NO2) | | 0.003348 | 0.0027153 | 0.0033818 |

Nitric Acid production
Source: all data

Technical report HDC-125-95 Pg 10
By Laurie J. Brown
Holston Defense Corporation
Subsidiary of Eastman Chemical Co.
Kingsport, TN 37660

| | | | Conc. wt frac. | Raw data in lb | kg per kg solution | kg per kg HNO3 | | | |
|---|---|---|---|---|---|---|---|---|---|
| Product | | | | | | | | | |
| | desired | Solution | | 2.031 | 1 | 3.3295082 | | | |
| | | HNO3 | 0.61 | | 0.61 | 1 | | | |
| | | W | 0.39 | | 0.39 | 0.6393443 | | | |
| Output | | | | | | | Oz troy | lb/Oz troy | (CRC '66) |
| | to Cat recovery | Plat Cat | | 2.715E-06 | | | 0.0000396 | 0.0685714 | |
| | | Pt | 0.9 | | 1.203E-06 | 4.006E-06 | | | |
| | | Pd | 0.05 | | 6.685E-08 | 2.226E-07 | | | |
| | | Rh | 0.05 | | 6.685E-08 | 2.226E-07 | | | |
| | to IWTF | NH3 | | 3.691E-05 | 1.817E-05 | 6.051E-05 | | | |
| Inputs | | | | | | | | | |
| | Materials | | | | | | | | |
| | | NH3 | | 0.3353 | 0.1650911 | 0.5496721 | | | |
| | | Air | | 6.53 | 3.2151649 | 10.704918 | | | |
| | | City Water | | 0.4369 | 0.2151157 | 0.7162295 | | | |
| | | Filtered Water | | 108.9 | 53.618907 | 178.52459 | Oz troy | lb/Oz troy | |
| | | Plat Cat | | 2.715E-06 | | | 0.0000396 | 0.0685714 | |
| | | Pt | 0.9 | | 1.203E-06 | 4.006E-06 | | | |
| | | Pd | 0.05 | | 6.685E-08 | 2.226E-07 | | | |
| | | Rh | 0.05 | | 6.685E-08 | 2.226E-07 | | | |
| | | Steam | | 0.2293 | 0.1129 | 0.3759016 | | | |
| | | River Water | | 54.42 | 26.794682 | 89.213115 | | | |
| | Energy | | | | | | | | |
| | | Electricity | kWhr | 0.1926 | 0.0948301 | 0.3157377 | | | |
| Waste | | | | | | | | | |
| | Water return to river (Non-contact) | | | 163.3 | 80.403742 | 267.70492 | | | |
| | Steam Condensate to river (Non-contact) | | | 0.2293 | 0.1129 | 0.3759016 | | | |
| Air Emiossion | | | | | | | | | |
| | | NOx (value is for NO2) | | 0.003348 | 0.0016484 | 0.0054885 | | | |

Nitric acid and Ammoniumnitrate synthesis
Area B Steam Plant
Source: for all data
Technical report HDC-125-95 Pg 26
By Laurie J. Brown
Holston Defense Corporation
Subsidiary of Eastman Chemical Co.
Kingsport, TN 37660

| | | Conc. | Raw data in lb | kg per kg Steam | kg per kg Steam | |
|---|---|---|---|---|---|---|
| Product | | | | | | |
| | Steam | | 50.75 | 1 | 1 | |
| | | | | | 0.9230959 | weighting according to coal utilization |
| Output | | | | | | |
| To Block Plant | Cinders | | 0.3436 | 0.0067704 | | |
| | Fly Ash | | 0.2655 | 0.0052315 | 0.0048292 | |
| to IWTF | Boiler blowdown | | 1.269 | 0.0250049 | 0.0230819 | |
| with: | Phosphates | | | | | |
| | Sulfates | | | | | |
| | Sulfites | | | | | |
| | Cooling Water | | 11.45 | 0.2256158 | 0.208265 | |
| with: | fly ash | | | | | |
| | cinders | | | | | |
| Inputs | | | | | | |
| Materials | | | | | | |
| | Coal | | 5.037 | 0.0992512 | 0.0916184 | |
| | Air | | 70.52 | 1.3895567 | 1.282694 | |
| | Filtered Water | | 63.43 | 1.2498522 | 1.1537334 | |
| | Boiler Guard | | 0.0002684 | 5.289E-06 | 4.882E-06 | Anionic polymer surfactant "BoilerGUARD APG", Calgon |
| | Conquor3475 | | 9.305E-05 | 1.833E-06 | 1.692E-06 | Diethylhydroxylamine, hydroquinone, Calgon |
| | C-1 Antifoam | | 8.459E-06 | 1.667E-07 | 1.539E-07 | Akoxylated alcohol solution, Calgon |
| | Rock Salt | | 0.01196 | 0.0002357 | 0.0002175 | |
| | Sulfuric acid | | 0.01408 | 0.0002774 | 0.0002561 | |
| Energy | | | | | | |
| | Electricity | kWhr | 0.1756 | 0.0034601 | 0.003194 | |
| Waste | | | | | | |
| | Fly Ash to Landfill | | 0.3036 | 0.0059823 | 0.0055222 | |
| Air Emiossion | | | | | | |
| | VOCs | | 0.0001261 | 2.485E-06 | 2.294E-06 | |
| | NOx | | 0.03451 | 0.00068 | 0.0006277 | |
| | CO | | 0.01259 | 0.0002481 | 0.000229 | |
| | SOx | | 0.09571 | 0.0018859 | 0.0017409 | |
| | Particulates | | 0.001209 | 2.382E-05 | 2.199E-05 | |
| | Flue gas | | 74.5 | 1.4679803 | 1.3550865 | |

Coal utilization breakdown for by product distribution

| | | lb/lb RDX |
|---|---|---|
| Coal | Coal | 5.037 |
| | Cinders | 0.3436 |
| | Ash | 0.5691 |

| | | |
|---|---|---|
| Energy coal | 4.1243 | 92.31% |
| Cinder Coal | 0.3436 | 7.69% |
| Utilized coal | 4.4679 | 100.00% |

Nitric acid and Ammoniumnitrate synthesis
Area B Water filtration
Source: for all data
Technical report HDC-125-95 Pg 30
By Laurie J. Brown
Holston Defense Corporation
Subsidiary of Eastman Chemical Co.
Kingsport, TN 37660

| | | | Conc. | Raw data in lb | kg per kg Filtered water |
|---|---|---|---|---|---|
| Product | | | | | |
| | | Filtered water | | 560.2 | 1 |
| Output | | | | | |
| to IWTF | | Water | | 27.17 | 0.0485005 |
| | with: | Alum | | 0.1154 | 0.000206 |
| | | Filter backwash | | 67.56 | 0.1205998 |
| | with: | | | | |
| Inputs | | | | | |
| | Materials | | | | |
| | | River water | | 655 | 1.1692253 |
| | | Hydrated lime | | 0.0008082 | 1.443E-06 |
| | | Al Sulfate | | 0.03795 | 6.774E-05 |
| | | Cl2 | | 0.002547 | 4.547E-06 |
| | Energy | | | | |
| | | Electricity | kWhr | 0.7422 | 0.0013249 |
| Waste | | | | | |
| Air Emiossion | | | | | |

Industrial Wastewater Treatment Facility
Both areas
Source: for all data
Technical report HDC-125-95 Pg 32
By Laurie J. Brown
Holston Defense Corporation
Subsidiary of Eastman Chemical Co.
Kingsport, TN 37660

| | | | Conc. | Raw data in lb | kg per kg wastewater | |
|---|---|---|---|---|---|---|
| Product | | | | | | |
| Output | | | | | | |
| Inputs | | | | | | |
| | Materials | | | | | |
| IWTF streams | | Wastewater | | 329.5 | 1 | |
| | | NaOH 20% | | 0.0314 | 9.53E-05 | |
| | | NaOH | 0.2 | 0.00628 | 1.906E-05 | |
| | | water | 0.8 | 0.02512 | 7.624E-05 | |
| | | Quicklime | | 0.002363 | 7.171E-06 | |
| | | FeCl2 25-35% | | 0.01109 | 3.366E-05 | |
| | | FeCl2 | 0.3 | 0.003327 | 1.01E-05 | |
| | | water | 0.7 | 0.007763 | 2.356E-05 | |
| | | HCl 33% | | 0.0002453 | 7.445E-07 | |
| | | HCl | 0.33 | 8.095E-05 | 2.457E-07 | |
| | | water | 0.67 | 0.0001644 | 4.988E-07 | |
| | | Magnifloc 496 | | 3.691E-05 | 1.12E-07 | flocculant |
| | | Filtered water | | 14.96 | 0.0454021 | |
| | Energy | | | | | |
| | | Electricity | kWhr | 0.2042 | 0.0006197 | |
| Waste | | | | | | |
| | | Treated Industrial waste water | | 344.3 | 1.0449165 | |
| | landfill | Biological sludge | | 0.1533 | 0.0004653 | |
| | landfill | Alum Sludge | | 0.1154 | 0.0003502 | |
| Air Emiossion | | | | | | |

**Sheet Title:** Diisopropyldiazodicarboxilate (from dichlorodiazodialdehyde ClOCNNCOCl and isopropanol. It is a precursor in production of TNAZ)

**Sheet Description:**
Emissions are from Engineering estimates, basic solvent is assumed to be pyridine at 2X excess and **NOT** recycled
Engineering calculation of the Energy requirements and precursor requirements .
Dichlorodiazodialdehyde manufacture from hydrazine and phosgene are included in the calculations
This page calculates the vendor emissions from a plant producing Diisopropyldiazodicarboxilate.
Not included are raw material production or extraction or water use.

**References/Citations:**


Perry's Chemical Engineers' Handbook, 6th ed.
McGraw Hill, 1984

AP 42 Ed 4 (1985)
US EPA

CRC Handbook of Chemistry and Physics, 66th Edition


Summary Output
Co-product Allocation Calculations

Source: US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993
US International Trade Commission, 11.1994

| Mwt | Co-product | Quantity | Units | Quantity | Units | 1993 Production | | | |
|---|---|---|---|---|---|---|---|---|---|
| 202.2096 | Diisopropyldiazodicarb | 1.00E+00 | kg | 1.00E+00 | kg | 17,859.00 | 88.3192489 | 17859 | 1 |
| | | | | | | 17,859.00 | | | |
| dichlorodiazodialdehyde | Total | 1.00 | Kg | 1.00E+00 | Kg | | | | |
| | | | | | | As acetone cyanohydrin | 60 | | |

Notes:

| LCI components | Unallocated Units | Quantity | Std. Dev. | Allocated Units | Quantity | Std. Dev. | DQI |
|---|---|---|---|---|---|---|---|
| **Air** | | | | | | | |
| Phosgene | Kg/kg Diazo | 5.71092E-05 | | Kg/kg Diazo | 5.71092E-05 | | 3 |
| Hydrazine | Kg/kg Diazo | 3.56014E-07 | | Kg/kg Diazo | 3.56014E-07 | | 3 |
| Isopropanol | Kg/kg Diazo | 6.19977E-07 | | Kg/kg Diazo | 6.19977E-07 | | 3 |
| Pyridine | Kg/kg Diazo | 5.58703E-06 | | Kg/kg Diazo | 5.58703E-06 | | 3 |
| HCl | Kg/kg Diazo | 1.0474E-05 | | Kg/kg Diazo | 1.0474E-05 | | 3 |
| **Wastewater** | | | | | | | |
| Phosgene | Kg/Kg Diazo | 0.009783551 | | Kg/kg Diazo | 0.009783551 | | 3 |
| Hydrazine | Kg/Kg Diazo | 0.001584742 | | Kg/kg Diazo | 0.001584742 | | 3 |
| Pyridine | Kg/Kg Diazo | 2.347069575 | | Kg/kg Diazo | 2.347069575 | **Without recycle** | 3 |
| Pyridine HCl | Kg/Kg Diazo | 3.428944026 | | Kg/kg Diazo | 3.428944026 | **Without recycle** | 3 |
| **Resource Consumption** | | | | | | | |
| Phosgene | Kg/kg Diazo | 0.978355132 | | Kg/kg Acetoni | 0.978355132 | | 3 |
| Hydrazine | Kg/kg Diazo | 0.158474177 | | Kg/kg Acetoni | 0.158474177 | | 3 |
| Isopropanol | Kg/kg Diazo | 0.594389188 | | Kg/kg Acetoni | 0.594389188 | | 3 |
| Cl2 | Kg/kg Diazo | 0.350655953 | | Kg/kg Acetoni | 0.350655953 | | 3 |
| Pyridine | Kg/kg Diazo | 4.694139151 | | Kg/kg Acetoni | 4.694139151 | | 3 |

Notes: This section is where the project specfic calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors

| Unit from | Unit to | Multiplier | Reference | |
|---|---|---|---|---|
| BTU | J | 1055.056 | CRC, 66th Edition | |
| Wh | J | 3600 | CRC, 66th Edition | |
| bbl CrO | BTU CrO | 5800000 | Chemical Engineers' Handbook, 6th ed. | |
| bbl | gal | 42 | Chemical Engineers' Handbook, 6th ed. | |
| gal diesel | BTU diesel | 118500 | Chemical Engineers' Handbook, 6th ed., Figure 9-4 @ S.G. = .76 and sulfur = 0.5% | |
| gal | L | 3.785412 | CRC, 66th Edition | |
| kg | lb | 2.2046226 | CRC, 66th Edition | |
| yr | day | 365 | | |
| m^3 | bbl (petroleum) | 6.289811 | CRC, 66th Edition | |
| gal CrO | lb CrO | 7.2 | | |
| ton | lb | 2000 | | |
| gal fuel oil | BTU fuel oil | 138000 | | |
| cu. ft NG | BTU NG | 1032 | Chemical Engineers' Handbook, 6th ed. | |
| lb Coal (dry | BTU Coal | 12000 | calculation page B | SD=11% |
| kg NG | MJ NG | 46 | Calculated page C | SD=13% |

| | | | | | | |
|---|---|---|---|---|---|---|
| Mw Benzen | 78.1134 | molar | | | | kg air per kg |
| Mw Chlorin | 70.9 | dry air composition | | Mwt | mass composition | component |
| Mw ClBz | 112.56 | N2 | 0.78084 | 28.0134 | 0.75521 | 1.324134 |
| Mw Cl2Bz | 147.01 | O2 | 0.20946 | 31.9988 | 0.231406 | 4.321406 |
| Mw HCl | 36.4609 | CO2 | 0.00033 | 44.01 | 0.000501 | 1994.319 |
| Mw NaOH 39.9971 | | Ar | 0.00934 | 39.948 | 0.012882 | 77.62792 |
| | | total | 0.99997 | 28.96409 | 1 | |

Ideal gas density at 15 C (60 F) — air (dry)

0.042296 mol/liter — 42.29634021 mol/m^3 — 1.225075 kg/m^3

Calculations

Process description

| HCl molecules produced | |
|---|---|
| 2 | Hydrazine and phosgene are mixed in 1:2 stoichiometric relationship in a cooled reactor containing a large excess of pyridine as a basic solvent. |
| 2 | Once conversion is complete Cl2 is bubbled through to react with the hydrogen bonds on the NN single bond. |
| 2 | Isopropanol is added in 2:1 stoichiometric ratio to the original hydrazine and reaction proceeds to final stage. |
| | Product solution is washed with water to remove pyridine and hydrochloric acid. |

99% Conversion is assumed due to strong driving force provided by HCl production during reaction.
1% unreacted

Co-Products: Given above.

**Resources:**

| **Energy Input** LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ nput Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| Fossil fuel (general) | MJ/kg Diazo | 0 | | | MJ/Kg Diazo | 0 | |

| | | | | | |
|---|---|---|---|---|---|
| Coal | MJ/kg Diazo | 0 | | Kg/kg Diazo | 0 |
| Oil | MJ/kg Diazo | 0 | 15 | Kg/kg Diazo | 0 |
| Natural Gas | MJ/kg Diazo | 0 | | Kg/kg Diazo | 0 |
| Hydropower | MJ/kg Diazo | 0 | | | 0 |
| Fission | MJ/kg Diazo | 0 | | | 0 |
| Electricity (generic) | MJ/kg Diazo | 7.060834755 | | MJ/Kg Diazo | 7.060834755 |

Energy requirement

Cal/mol MJ/kg Diazo

Reaction temperature is assumed to be kept constant by removal of all heat formed during the reaction

Electric Demand

| | | | |
|---|---|---|---|
| Electricity | refrigeration of reaction tank MJ/Kg | 4.942584328 | **7.060834755** heat energy to disperse is calculated from HCl formation only. |
| | efficiency of refrigeration electricity | 0.7 | |

7.8726E-08 MJ Elec/Kg Based on viscosity and density of water for a 250 ft static head per pumping stage in 40hr week & 52 week year daytime operation. multiply by specific gravity of material and relative viscosity to that of water.

These are guesses

| | | |
|---|---|---|
| Coolers | #REF! | |
| Total | #REF! | MJ/Kg Diazo |

source: Stoichiometric calculations

**Material Input**

| | LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ nput Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|---|
| | Oil | Kg/kg Diazo | 0 | | 4 | Kg/kg Diazo | 0 | |
| | Natural Gas | Kg/kg Diazo | 0 | | 4 | Kg/kg Diazo | 0 | |
| | Coal | Kg/kg Diazo | 0 | | 4 | Kg/kg Diazo | 0 | |
| 98.9164 | Phosgene | Kg/kg Diazo | 0.978355132 | | 4 | Kg/kg Diazo | 0.978355132 | |
| 32.045 | Hydrazine | Kg/kg Diazo | 0.158474177 | | 4 | Kg/kg Diazo | 0.158474177 | |
| 60.0956 | Isopropanol | Kg/kg Diazo | 0.594389188 | | 4 | Kg/kg Diazo | 0.594389188 | |
| 70.906 | Cl2 | Kg/kg Diazo | 0.350655953 | | 4 | Kg/kg Diazo | 0.350655953 | |
| 79.1 | Pyridine | 2 Kg/kg Diazo | 4.694139151 | | 5 | Kg/kg Diazo | 4.694139151 | |
| | Water | Kg/kg Diazo | 0 | | 4 | Kg/kg Diazo | 0 | |

**Air**

| Vapor P mmHg @ 25 C | LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ nput Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. | Partial P mmHg @ 25 C |
|---|---|---|---|---|---|---|---|---|---|
| | TSP | Kg/Kg Diazo | 0 | | 3 | Kg/kg Diazo | 0 | | |
| | SOx | Kg/Kg Diazo | 0 | | 3 | Kg/kg Diazo | 0 | | |
| | NOx | Kg/Kg Diazo | 0 | | 3 | Kg/kg Diazo | 0 | | |
| 1428 | Phosgene | Kg/Kg Diazo | 5.71092E-05 | | 3 | Kg/kg Diazo | 5.71092E-05 | | 2.1743 |
| 169.6428571 | Hydrazine | Kg/Kg Diazo | 3.56014E-07 | | 3 | Kg/kg Diazo | 3.56014E-07 | | 0.0418 |
| 42 | Isopropanol | Kg/Kg Diazo | 6.19977E-07 | | 3 | Kg/kg Diazo | 6.19977E-07 | | 0.0389 |
| gas | Cl2 | Kg/Kg Diazo | 0 | | 3 | Kg/kg Diazo | 0 | | |
| 24.27419355 | Pyridine | Kg/Kg Diazo | 5.58703E-06 | | 3 | Kg/kg Diazo | 5.58703E-06 | | 0.2660 |
| 36480 | HCl | Kg/Kg Diazo | 1.0474E-05 | | 3 | Kg/kg Diazo | 1.0474E-05 | | 1.0819 |
| | HC total | Kg/Kg Diazo | 0 | | 3 | Kg/kg Diazo | 0 | | |
| | Heavy meta(Cd+Ni+Cr) | Kg/Kg Diazo | 0 | | 3 | Kg/kg Diazo | 0 | | Total volatiles |
| | | | | | | | | | 6.4254 |

d Pyridine 981.9 kg/m^3 assumed volume in condenser is pyridine
0.004781 m^3 0.201801 mol gas

**Water**

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ nput Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| COD | Kg/Kg Diazo | 0 | | 3 | Kg/kg Diazo | 0 | |
| BOD | Kg/Kg Diazo | 0 | | 3 | Kg/kg Diazo | 0 | |
| Acid, H+ (Phosphoric) | Kg/Kg Diazo | 0 | | 3 | Kg/kg Diazo | 0 | |
| Metal ions | Kg/Kg Diazo | 0 | | 3 | Kg/kg Diazo | 0 | |
| Cl2 | Kg/Kg Diazo | 0 | | 3 | Kg/kg Diazo | 0 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Phosgene | Kg/Kg Diazo | 0 | | 3 | Kg/kg Diazo | 0 | |
| Hydrazine | Kg/Kg Diazo | 0 | | 3 | Kg/kg Diazo | 0 | |
| Isopropanol | Kg/Kg Diazo | 0 | | 3 | Kg/kg Diazo | 0 | |
| Cl2 | Kg/Kg Diazo | 0 | | 3 | Kg/kg Diazo | 0 | |
| Pyridine | Kg/Kg Diazo | 0 | | 3 | Kg/kg Diazo | 0 | |
| Pyridine HCl | Kg/Kg Diazo | 0 | | 3 | Kg/kg Diazo | 0 | |

**Solid waste**

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ nput Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| Production waste (not innert) | Kg/Kg Diazo | 0 | | 5 | Kg/kg Diazo | 0 | |
| Diazo | Kg/Kg Diazo | 0 | | 5 | Kg/kg Diazo | 0 | |
| Pyridine | Kg/Kg Diazo | 0 | | | Kg/kg Diazo | 0 | |
| Heavy metals (Cadmium, Nickel, C | Kg/Kg Diazo | 0 | | 5 | Kg/kg Diazo | 0 | |

**Deep well Injection**

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ nput Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| Diazo | Kg/Kg Diazo | 0 | | | Kg/kg Diazo | 0 | |
| Phosgene | Kg/Kg Diazo | 0.009783551 | | | Kg/kg Diazo | 0.009783551 | |
| Hydrazine | Kg/Kg Diazo | 0.001584742 | | | Kg/kg Diazo | 0.001584742 | |
| Pyridine | Kg/Kg Diazo | 2.347069575 | | | Kg/kg Diazo | 2.347069575 | **Without recycle** |
| Pyridine HCl | Kg/Kg Diazo | 3.428944026 | | | Kg/kg Diazo | 3.428944026 | **Without recycle** |

Sheet End ======== ================ ============= =========== ========== ========== ============= ============ ========== ================== ======= =======

| | |
|---|---|
| Sheet Title: | Phosgene (from chlorine and carbon monoxide. Phosgene is used in production of TNAZ precursor diisopropyldiazodicarboxylate) |
| Sheet Description: | Emissions are from TRI database.<br>Engineering calculation of the Energy requirements and precursor requirements .<br>This page calculates the vendor emissions from a plant producing Phosgene.<br>Not included are raw material production or extraction or water use. |
| References/Citations: | Faith Keyes and Clarke's Industrial Chemicals<br>By F. A. Lowenheim, M. K. Moran<br>Wiley Interscience, 1975 |
| | Perry's Chemical Engineers' Handbook, 6th edSource for physical data and unit conversions<br>McGraw Hill, 1984 |
| | CRC Handbook of Chemistry and Physics, 66thSource for physical data and unit conversions |
| | AP 42 Ed 4 (1985)<br>US EPA |
| | SRI Directory of Chemical Producers, US<br>1993, 1991 editions<br>SRI International, Menlo Park, CA |

Summary Output -------------------- ------------------ ------------------ ------------------ ------------------ ---------------------- --------------------- ------------------

Co-product Allocation Calculations

Source: US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993
US International Trade Commission, 11.1994

| Mwt | Co-product | Quantity | Units | Quantity | Units | BP deg C | Sp G | Vapor density relative to air |
|---|---|---|---|---|---|---|---|---|
| 98.92 | Phosgene | 1.00E+00 | kg | 1.00E+00 | kg | 8.2 | 1.392 | 3.4 |
| | Total | 1.00E+00 | Kg | 1.00E+00 | Kg | | | |

Notes:

| LCI components | Unallocated Units | Quantity | Std. Dev. | Allocated Units | Quantity | Std. Dev. | DQI |
|---|---|---|---|---|---|---|---|
| **Air** | | | | | | | |
| Cl2 | Kg/kg Phosgen | 1.41667E-05 | | Kg/kg Phosgen | 1.41667E-05 | | 5 |
| CO | Kg/kg Phosgen | 5.59634E-06 | | Kg/kg Phosgen | 5.59634E-06 | | 5 |
| Phosgene | Kg/kg Phosgen | 5.55556E-07 | | Kg/kg Phosgen | 5.55556E-07 | | 5 |

| | | | | | |
|---|---|---|---|---|---|
| HCl | Kg/kg Phosgen | 5.55556E-07 | Kg/kg Phosgen | 5.55556E-07 | 5 |

**Water**

Solid Wastes

Resource Consumption

| | | | | |
|---|---|---|---|---|
| CO | Kg/kg Phosgen | 0.23 | Kg/kg Phosgen | 0.23 |
| Cl2 | Kg/kg Phosgen | 0.72 | Kg/kg Phosgen | 0.72 |
| Activated Carbor | Kg/kg Phosgen | 0.0005 | Kg/kg Phosgen | 0.0005 |

Notes: This section is where the project specfic calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors

| Unit from | Unit to | Multiplier | Reference | |
|---|---|---|---|---|
| BTU | J | 1055.056 | CRC, 66th Edition | |
| Wh | J | 3600 | CRC, 66th Edition | |
| bbl CrO | BTU CrO | 5800000 | Chemical Engineers' Handbook, 6th ed. | |
| bbl | gal | 42 | Chemical Engineers' Handbook, 6th ed. | |
| gal diesel | BTU diesel | 118500 | Chemical Engineers' Handbook, 6th ed., Figure 9-4 @ S.G. = .76 and sulfur = 0.5% | |
| gal | L | 3.785412 | CRC, 66th Edition | |
| kg | lb | 2.2046226 | CRC, 66th Edition | |
| yr | day | 365 | | |
| m^3 | bbl (petroleum) | 6.289811 | CRC, 66th Edition | |
| gal CrO | lb CrO | 7.2 | | |
| ton | lb | 2000 | | |
| gal fuel oil | BTU fuel oil | 138000 | | |
| cu. ft NG | BTU NG | 1032 | Chemical Engineers' Handbook, 6th ed. | |
| lb Coal (dry | BTU Coal | 12000 | calculation page B | SD=11% |
| kg NG | MJ NG | 46 | Calculated page C | SD=13% |

| | |
|---|---|
| Mw Benzen | 78.1134 |
| Mw Chlorin | 70.9 |
| Mw ClBz | 112.56 |
| Mw Cl2Bz | 147.01 |
| Mw HCl | 36.4609 |
| Mw NaOH | 39.9971 |

| molar dry air composition | | Mwt | mass composition | kg air per kg component |
|---|---|---|---|---|
| N2 | 0.78084 | 28.0134 | 0.75521 | 1.324134 |
| O2 | 0.20946 | 31.9988 | 0.231406 | 4.321406 |
| CO2 | 0.00033 | 44.01 | 0.000501 | 1994.319 |
| Ar | 0.00934 | 39.948 | 0.012882 | 77.62792 |
| total | 0.99997 | 28.96409 | 1 | |

Ideal gas density at 15 C (60 F) air (dry)

| | | | |
|---|---|---|---|
| | 0.042296 mol/liter | 42.29634021 mol/m^3 | 1.225075005 kg/m^3 |
| Calculations | | | |

**Phosgene Production** 1993

Source: None

**Phosgene production capacity**

Source: SRI 1991 Directory of Chemical Producers, US

| | | Capacity Mlb | Calculated production: Mlb |
|---|---|---|---|
| | Mlb | 2290 | |
| Utilization ratio: | chemical industry average 199 | 0.9 | |
| Van de Mark Chemical Com | Lockport, NY 14094 | 20 | 18 |
| Olin Corporation | Lake Charles, LA 70602 | 254 | 228.6 |
| BASF Corporation | Geismar, LA 70734 | 320 | 288 |
| Miles Inc. | Baytown TX 77520 | 450 | 405 |

Source: Emissions:

TRI database, 1993 data

The Van de Mark plant is the only manufacturer of phosgene for open sale on the market so only its TRI data are used

The following reported emissions were ascribed to Phosgene production of

| | | Phosgene | Chlorine | Carbon monoxide | HCl |
|---|---|---|---|---|---|
| Van de Mark Chemical Com | Lockport, NY 14094 | 5.56E-07 | 1.42E-05 | | 5.56E-07 |
| Olin Corporation | Lake Charles, LA 70602 | 1.71E-07 | 1.30E-04 | | 2.42E-05 |
| BASF Corporation | Geismar, LA 70734 | 2.43E-08 | 7.29E-08 | | 2.57E-04 |
| Miles Inc. | Baytown TX 77520 | 6.30E-07 | 1.98E-05 | | 1.06E-05 |
| | | 1.133333333 | 1.394335512 | | 9.84265E-06 |

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| Fossil fuel (general) | MJ/kg Phosgen | 0 | | | MJ/kg Phosgene | 0 | |
| Coal | MJ/kg Phosgen | 0 | | | Kg/kg Phosgene | 0 | |
| Oil | MJ/kg Phosgen | 0 | | | Kg/kg Phosgene | 0 | |
| Natural Gas | MJ/kg Phosgen | 0 | | | Kg/kg Phosgene | 0 | |
| Hydropower | MJ/kg Phosgen | 0 | | | | | |
| Fission | MJ/kg Phosgen | 0 | | | | | |
| Electricity (generic) | MJ/kg Phosgen | 0.375737838 | | | MJ/kg Phosgene | 0.375737838 | |

Cooling water

25 deg C temp rise

0.104482 heat removal MJ/kg water 0.004179285 heat capacity MJ/Kg/deg C (see pCl3 sheet)

| | | | | |
|---|---|---|---|---|
| | 0.263016 MJ/kg product | 6224.3 D Hvap CCl2Ocal/mol | 0.263016316 MJ/Kg phosgene | |
| c water | 2.517333 Kg/Kg product | | 0.375737595 Refrigeration electricity usage fo | 0.7 efficiency |

7.87E-05 kJ Elec/Kg — Based on viscosity and density of water for a 250 ft static head per pumping stage in 40hr week & 52 week year daytime operation. multiply by specific gravity of material and relative viscosity to that of water.

| | | representative m | Sp grav | Sp visc | kgflow/kg prod | | |
|---|---|---|---|---|---|---|---|
| condenser | to storage | Phosgene | 1.392 | 1.5 | MJ/kg Phosgen | 1.6438E-07 | viscosity is a guess |
| distillation | to treatmen | Phosgene solutio | 1 | 1 | Chlorine | 7.8726E-08 | viscosity is a guess |
| cooling water | | | 1 | 1 | 2.517332912 | 0 | |
| | | | | | | 2.43106E-07 | total pumping energy per kg prod |

Co-Products:

source: See from above

Resources: Faith, Keyes and Clark'e Industrial chemicals

| | LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|---|
| | Oil | Kg/kg Phosgen | 0 | | 4 | Kg/kg Phosgene | 0 | |
| | Natural Gas | Kg/kg Phosgen | 0 | | 4 | Kg/kg Phosgene | 0 | |
| | Coal | Kg/kg Phosgen | 0 | | 4 | Kg/kg Phosgene | 0 | |
| 28.0104 | CO | m^3/kg Phosge | 0.23 | | 4 | Kg/kg Phosgene | 0.23 | |
| 70.906 | Cl2 | Kg/kg Phosgen | 0.72 | | 4 | Kg/kg Phosgene | 0.72 | |
| 12.011 | Activated Carbon | Kg/kg Phosgen | 0.0005 | | 4 | Kg/kg Phosgene | 0.0005 | |
| | Air | Kg/kg Phosgen | 0 | | 4 | Kg/kg Phosgene | 0 | |
| | Water | Kg/kg Phosgen | 0 | | 4 | Kg/kg Phosgene | 0 | |

**Air**

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. | |
|---|---|---|---|---|---|---|---|---|
| TSP | Kg/kg Phosgen | 0 | | | Kg/kg Phosgene | 0 | | |
| SOx | kg/kg Phosgen | 0 | | | Kg/kg Phosgene | 0 | | |
| NOx | kg/kg Phosgen | 0 | | | Kg/kg Phosgene | 0 | | |
| Cl2 | kg/kg Phosgen | 1.42E-05 | | | Kg/kg Phosgene | 1.41667E-05 | | |
| CO2 | kg/kg Phosgen | 0 | | 3 | Kg/kg Phosgene | 0 | | |
| CO | kg/kg Phosgen | 5.59634E-06 | | | Kg/kg Phosgene | 5.59634E-06 | | Industrial practice is to leave excess |
| Phosgene | kg/kg Phosgen | 5.56E-07 | | | Kg/kg Phosgene | 5.55556E-07 | | |
| HCl | kg/kg Phosgen | 5.56E-07 | | | Kg/kg Phosgene | 5.55556E-07 | | |
| HC total | kg/kg Phosgen | 0 | | | Kg/kg Phosgene | 0 | | |
| Heavy meta(Cd+Ni+Cr) | kg/kg Phosgen | 0 | | | Kg/kg Phosgene | 0 | | |

**Water**

| Raw/ | Raw/ | Raw/ | Transformed | Transformed | Transformed |
|---|---|---|---|---|---|

| LCI component | Input Units | Input Quan. | Input Std. Dev. | DQI | Units | Quan. | Std. Dev. |
|---|---|---|---|---|---|---|---|
| COD | kg/kg Phosgen | 0 | | 5 | Kg/kg Phosgene | 0 | |
| BOD | kg/kg Phosgen | 0 | | 5 | Kg/kg Phosgene | 0 | |
| Acid, H+ (Phosphoric) | kg/kg Phosgen | 0 | | 5 | Kg/kg Phosgene | 0 | |
| Metal ions | kg/kg Phosgen | 0 | | 5 | Kg/kg Phosgene | 0 | |
| Cl2 | kg/kg Phosgen | 0 | | 5 | Kg/kg Phosgene | 0 | |
| CO2 | kg/kg Phosgen | 0 | | 5 | Kg/kg Phosgene | 0 | |
| CO | kg/kg Phosgen | 0 | | 5 | Kg/kg Phosgene | 0 | |
| Phosgene | kg/kg Phosgen | 0 | | 5 | Kg/kg Phosgene | 0 | |
| HCl | kg/kg Phosgen | 0 | | 5 | Kg/kg Phosgene | 0 | |
| Heavy metals (Cadmium, Ni | kg/kg Phosgen | 0 | | 5 | Kg/kg Phosgene | 0 | |

**Solid waste**

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| Production waste (not innert | kg/kg Phosgen | 0 | | 5 | Kg/kg Phosgene | 0 | |
| Heavy metals (Cadmium, Ni | kg/kg Phosgen | 0 | | 5 | Kg/kg Phosgene | 0 | |

Sheet End

**Sheet Title:** Ammonia (data for fertilizer production, applied to nitric acid production)

**Sheet Description:** This page calculates the vendor-independent emissions from US plants producing fertilizer quality Ammonia. Oil and Natural gas extraction and transportation are not included.

**References/Citations:**


U.S. EPA. 1995. AP-42, Fifth Edition, Table 8.1-1.

Energy Information Administration. 1994. Manufacturing Consumption of Energy: 1991, DOE/EIA 0512(91).

United States Environmental Protection Agency. 1995. Compilation of Air Pollutant Emission Factors, AP-42.

United States Department of Energy, Energy Information Administration. 1994. Emissions of Greenhouse Gases in the U.S.: 1987-1992, DOE/EIA-0573.

United States Department of Energy, Energy Information Administration. 1993. Annual Energy Review: 1993, DOE/EIA-0384(93).


**Summary Output**

Co-product Allocation Calculations

| Co-product | Quantity | Units |
|---|---|---|
| Ammonia | 1.00E+00 | kg |
| Total | 1 | kg |

**Notes:** Bbl eq. are calculated on a energy content basis and used to calcualte the allocated LCI emissions factors. Bbl. of CrO production are scaled by multiplying by the ratio of bbl eq. CrO produced to bbl CrO produced.

**LCI components**

| | | Unallocated Units | Quantity | Std. Dev. | Allocated Units | Quantity | Std. Dev. | DQI |
|---|---|---|---|---|---|---|---|---|
| | Air | | | | | | | |
| | TSP (PM-10) | Kg/Kg Ammon | 5.90939E-10 | | kg/kg TNAZ | | | 4 |
| | SOx | Kg/Kg Ammon | 2.88E-05 | | kg/kg TNAZ | | | 4 |
| | NOx | Kg/Kg Ammon | 6.13238E-09 | | kg/kg TNAZ | | | 4 |
| | CO | Kg/Kg Ammon | 0.007900001 | | kg/kg TNAZ | | | 4 |
| | CO2 | Kg/Kg Ammon | 1.2234 | | kg/kg TNAZ | | | 4 |
| | Ammonia | Kg/Kg Ammon | 0.0021 | | kg/kg TNAZ | | | 4 |
| | Methane | Kg/Kg Ammon | 7.47036E-10 | | kg/kg TNAZ | | | 4 |
| | other organic | Kg/Kg Ammon | 0.004720003 | | kg/kg TNAZ | | | 4 |
| | Water | | | | | | | |
| | Solid Wastes | | | | | | | |
| | Resource Consumption | | | | | | | |
| | Natural Gas | Kg/Kg Ammon | 0.549481458 | | | | | 4 |
| fuel | Natural Gas | Kg/Kg Ammon | 0.5057511 | | | | | 4 |
| | Electric Power | MJ/kg Ammon | 1.1 | | | | | 4 |
| | steam | MJ/kg Ammon | 0.38 | | | | | 4 |

**Notes:** This section is where the project specfic calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Table 35 Process Related Emissions from Ammonia Manufacture for Nitrogenous Fertilizers

U.S. EPA. 1995. AP-42, Fifth Edition, Table 8.1-1.

| | lb/ton of ammonia produced | | | | |
|---|---|---|---|---|---|
| Emission Source | CO | SO2 | NH3 | CO2 | Total Organic Compounds |
| Desulferization Unit | 13.8 | 0.0576 | | | 7.2 |
| Carbon Dioxide Regenerator | 2 | | 2 | 2,440 | 1.04 |
| Condensate Steam Stripper | | | 2.2 | 6.8 | 1.2 |
| Total | 15.8 | 0.0576 | 4.2 | 2446.8 | 9.44 |
| In units of | Kg/Kg ammonia | | | | |
| Total | 0.0079 | 0.0000288 | 0.0021 | 1.2234 | 0.00472 |

Notes: Since we know the amount of methane (and hence carbon) used as a feedstock for Ammonia production one can calculate a bound on process related CO2 emissions.

| | | | | |
|---|---|---|---|---|
| Feedstock Methane Use | 21.78 | million btu/ton ammonia | 0.024008094 | million btu/kg ammonia |
| | 26.48222965 | million btu/ton N | 1.055232558 | kg/ kg Ammonia |
| | 13241.11482 | Btu/lb N | | |
| Carbon per unit Methane | 14.47 | Million metric tons C/quad | | |
| | 31.900562 | lb C/million btu | | |
| | 116.8876325 | lb CO2/million btu | | |
| | 1.547722563 | lb CO2/lb N | | |
| | 3095.445126 | lb CO2/ton N | | |

This shows that the CO2 emission factors for process related emissions are based on the carbon value of the feedstock, and the assumption that virtually all carbon is emitted, not used for other purposes.

Emissions from Energy Consumption in Ammonia Manufacture

Energy Information Administration. 1994. Manufacturing Consumption of Energy: 1991, DOE/EIA 0512(91).

United States Environmental Protection Agency. 1995. Compilation of Air Pollutant Emission Factors, AP-42.

United States Department of Energy, Energy Information Administration. 1994. Emissions of Greenhouse Gases in the U.S.: 1987-1992, DOE/EIA-0573.

United States Department of Energy, Energy Information Administration. 1993. Annual Energy Review: 1993, DOE/EIA-0384(93).

Energy for Nonfuel Purposes (MECS Table A3)

| Nitrogenous Fertilizers | Raw Input Quantity | Units | Transformed Input Quantity | Units | Notes: |
|---|---|---|---|---|---|
| Natural Gas | 289 | Tbtu | 52.07% | Feedstock Share | |
| Total | 290 | Tbtu | | | |

Energy for Heat, Power, etc. (MECS Table A4)

| | | | | |
|---|---|---|---|---|
| Natural Gas | 266 | Tbtu | 0.479279279 | Fuel Share |
| Electricity | 10 | Tbtu | | |
| Other | 4 | Tbtu | | |

Total Primary Energy Consumption (MECS Table A1)

| | | |
|---|---|---|
| Natural Gas | 555 | Tbtu |
| Electricity | 10 | Tbtu |
| Other | 568 | Tbtu |

Large Industrial Boiler Emission Factors (AP-42, Tables 1.4-1 to 1.4-3)
Natural gas powered heat source

| | | | | | | |
|---|---|---|---|---|---|---|
| SO2 | | 0.6 | lb/million cubic ft | 0.00058 | lb/million btu | |
| NOx | Uncontrolled | 550 | lb/million cubic ft | 0.53295 | lb/million btu | |
| | Controlled-Lo NOx | 81 | lb/million cubic ft | 0.07849 | lb/million btu | |
| | Controlled-FGR | 53 | lb/million cubic ft | 0.05136 | lb/million btu | |
| | Average Controlle | 67 | lb/million cubic ft | 0.06492 | lb/million btu | |
| | Average | 308.5 | lb/million cubic ft | 0.29893 | lb/million btu | |
| CO | | 40 | lb/million cubic ft | 0.03876 | lb/million btu | |
| PM-10 | | 13.7 | lb/million cubic ft | 0.01328 | lb/million btu | This factor is given as the sum of filterable and condensible particulate. All PM emissions from N.G. consumption are thought to be < 10 microns in diameter |
| Methane | | 0.289 | lb/million cubic ft | 0.00028 | lb/million btu | |
| Non-methane VOC's | | 1.41 | lb/million cubic ft | 0.00137 | lb/million btu | |
| CO2 | | 14.47 | million metric ton | 116.9 | lb/million btu | |
| Heat Content of Natural Gas (AER, Table A | | 1,032 | Btu/cubic foot | | | |

Emissions from the Use of N.G. in the Manufacture of Ammonia

| | | |
|---|---|---|
| SO2 | 6.69E-12 | kg/kg ammonia |
| NOx | 6.13E-09 | kg/kg ammonia |
| CO | 9.03E-10 | kg/kg ammonia |
| PM-10 | 5.91E-10 | kg/kg ammonia |
| Methane | 7.47E-10 | kg/kg ammonia |
| Non-methane VOC's | 3.44E-09 | kg/kg ammonia |
| CO2 | 4.46E-10 | kg/kg ammonia |

Notes: The share of N.G. used as feedstock for Ammonia vs. fuel is used to reduce emissions estimates to account for N.G. not consumed in boilers.

Emission factors are converted into units of lb/million btu, which are multiplied by energy consumption and share of energy used as fuel.
Emissions from the consumption of electricity by the industry will be calculated by the electricity module.

N.G. is used as a feedstock through a reforming process to produce hydrogen gas. This is the predominant process for ammonia production in the U.S.
The hydrogen is reacted with nitrogen to form ammonia. This process results in the production of carbon dioxide and carbon monoxide.
Carbon monoxide can be converted back to carbon dioxide through the water-gas shift reaction. Carbon dioxide has
industrial use in several areas including the manufacture of urea from ammonia,
but some carbon dioxide is emitted from the process. These and other process related emissions are treated in Table 25.

Source:
Bhat, Mahadev G., Burton C. English, Anthony Turhollow, and Herzron Nyangito. 1993. Energy Use in Synthetic Agricultural Inputs: Revisited,
Report prepared by the Department of Agricultural Economics and Rural Sociology, The University of Tennessee, Knoxville, for Biofuels Feedstock Development Program
Environmental Sciences Division, Oak Ridge National Laboratory, ORNL/Sub/90-99732/2.

Energy Requirements for Fertilizer Production

| | Natural Gas | Electricity | Oil | Steam | Exported Steam | Total | |
|---|---|---|---|---|---|---|---|
| Anhydrous Ammonia | 40.79 | 1.1 | 0 | 0 | 0.38 | 41.51 | (GJ/metric ton) |
| | 38693.394 | 1043.46 | 0 | 0 | 360.468 | 39376.386 | Btu/kg |
| | kg/kg Ammonia | MJ/kg Ammonia | | | | | |
| | 17.00698487 | 1.1 | | | | | |

Notes: Taken from Table 16 (p. 26).

| Unit from | Unit to | Multiplier | Name | Source: | | |
|---|---|---|---|---|---|---|
| bu | lb | 56 | lb_bu | | | |
| Hectares | acre | 2.471 | acre_hect | | | |
| kg | lb | 2.2046 | lb_kg | | | |
| hectares | sq. meters | 10,000 | sqmeters_hect | | | |
| meter | feet | 3.281 | feet_meter | | | |
| short tons | lb | 2000 | lb_shortton | | | |
| metric tons | kg | 1000 | kg_mton | | | |
| kcal | btu | 3.968 | btu_kcal | | | |
| Joules | btu | 9.49E-04 | btu_joule | | | |
| Gallons Ethanol | lb | 6.6 | lb_gallon | | | |
| Gallons Ethanol | bu | 0.4 | bu_gallon | | | |
| Hectares | Sq. cm | 1.00E+08 | sqcm_ha | | | |
| cubic cm | liters | 0.001 | liters_ccm | | | |
| liters | gallons | 0.264 | gallons_liter | | | |
| sq mile | acres | 640 | acres_sqmile | | | |
| metric tons | short tons | 1.102 | shortton_metricton | | | |
| barrels | gallons | 42 | gallons_barrel | | 0 | |
| kg | grams | 1,000 | grams_kg | | | |
| cubic foot natural g | btu | 1,032 | btu_cubicft | | 0 | |
| barrel distillate fue | million btu | 5.825 | btu_barreloil | | 0 | 138,690 |
| barrel motor gasol | million btu | 5.253 | btu_barrelgas | | 0 | 125,071 |
| Short ton coal | million btu | 22.25 | Btu_toncoal | | 0 | |
| Barrel LPG | million btu | 3.614 | Btu_barrellpg | | | 86,048 |

Molecular Wts.

| | | |
|---|---|---|
| | H | 1.008 |
| | Ca | 40.08 |
| | O | 16.00 |
| | S | 32.06 |
| | C | 12.01 |
| | Cl | 35.45 |
| | K | 39.10 |
| | P | 30.97 |
| | N | 14.01 |
| | $K_2O$ | 94.20 |
| | KCl | 74.56 |
| | $CO_2$ | 44.01 |
| | $CaSO_4$ | 136.14 |
| | $H_2SO_4$ | 98.07 |
| | $P_2O_5$ | 141.94 |
| | $HNO_3$ | 63.01 |
| | $NH_4NO_3$ | 80.04 |

Sheet Title: soda caustic

Sheet Description: This page calculates the vendor-independent emissions from european manufacture of caustic soda .

References/Citations: SimaPro3 (entry of Nov 18 94)
Average european data for NaOH/Cl2 producers.
taken from:
PWMI/APME, Ecoprofiles of the European plastics industry, 1992-1994
report 6, tbl 15 pg 13 and report 5 (allocation)

Summary Output

Co-product Allocation Calculations

| Co-product | Quantity | Units | |
|---|---|---|---|
| NaOH | 1.00E+00 | Kg | |
| Chlorine | | | data after allocation |
| Total | 1 | Kg | |

| LCI components | | Unallocated Units | Quantity | Std. Dev. | Allocated Units | Quantity | Std. Dev. | DQI |
|---|---|---|---|---|---|---|---|---|
| Air | | | | | | | | |
| | COD | Kg/Kg soda caus | 0.074 | | | | | 3 |
| | BOD | Kg/Kg soda caus | 0.00002 | | | | | 3 |
| | Acid as H+ | Kg/Kg soda caus | 0.007 | | | | | 3 |
| | Nitrate | Kg/Kg soda caus | 0.0008 | | | | | 3 |
| | Metal ions | Kg/Kg soda caus | 1.21 | | | | | 3 |
| | Cl2 | Kg/Kg soda caus | 0 | | | | | 3 |
| | ammonia | Kg/Kg soda caus | 0.00018 | | | | | 3 |
| | dissolved organi | Kg/Kg soda caus | 0.006 | | | | | 3 |
| | Crude | Kg/Kg soda caus | 0.000002 | | | | | 3 |
| | dissolved substa | Kg/Kg soda caus | 0.00005 | | | | | |
| | HC's | Kg/Kg soda caus | 0 | | | | | |
| | unknown (N) | Kg/Kg soda caus | 0.0028 | | | | | |
| Water | | | | | | | | |
| | COD | Kg/Kg soda caus | 0.00001 | | | | | 3 |
| | BOD | Kg/Kg soda caus | 0.000003 | | | | | 3 |
| | Acid as H+ | Kg/Kg soda caus | 0.00034 | | | | | 3 |
| | Metal ions | Kg/Kg soda caus | 0.00009 | | | | | 3 |

| | | | | | |
|---|---|---|---|---|---|
| | Cl2 | Kg/Kg soda caus | 0.042 | | 3 |
| | Dissolved Organ | Kg/Kg soda caus | 0 | | 3 |
| | suspended solid | Kg/Kg soda caus | 0.002 | | 3 |
| | crude oil | Kg/Kg soda caus | 0 | | 3 |
| | miscelanious dis | Kg/Kg soda caus | 0.00005 | | 3 |
| | total HC's | Kg/Kg soda caus | 0 | | |
| | sodium | Kg/Kg soda caus | 0.0028 | | 3 |
| | Solid Wastes | | | | |
| | Production waste | Kg/Kg soda caus | 0.099 | | 3 |
| Resource Consumption | | | | | |
| fuel | Natural Gas | Kg/Kg soda caus | 0.176505121 | 6766029.629 | 3 |
| fuel | Crude Oil | Kg/Kg soda caus | 0.129783177 | 23.09245495 | 3 |
| | Coal | Kg/Kg soda caus | 0 | | |
| fuel | Coal | MJ/Kg soda caus | 0.217294119 | 38.66336743 | 3 |
| | Hydropower | MJ/Kg soda caus | 0.734851726 | | |
| | Fission | | 5.940913952 | | |
| | Iron ore | Kg/Kg soda caus | 0.00046 | | |
| | limestone | Kg/Kg soda caus | 0.0105 | | |
| | Rock salt | Kg/Kg soda caus | 0.59 | | |
| | Water | Kg/Kg soda caus | 5.3 | | |
| | sand | | 0.00002 | | |

Notes: This section is where the project specfic calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors

| Unit from | Unit to | Multiplier | Reference |
|---|---|---|---|
| | | 1055.056 | |
| BTU | J | 3600 | CRC, 66th Edition |
| Wh | J | 5800000 | CRC, 66th Edition |
| bbl CrO | BTU CrO | 42 | Chemical Engineers' Handbook, 6th ed. |
| bbl | gal | 118500 | Chemical Engineers' Handbook, 6th ed. |
| gal diesel | BTU diesel | 3.785412 | Chemical Engineers' Handbook, 6th ed., Figure 9-4 @ S.G. = .76 and sulfur = 0.5% |
| gal | L | 2.2046226 | CRC, 66th Edition |
| kg | lb | 365 | CRC, 66th Edition |
| yr | day | 6.289811 | |
| m^3 | bbl (petroleum) | 7.2 | CRC, 66th Edition |
| gal CrO | lb CrO | 2000 | |
| ton | lb | 138000 | |
| gal fuel oil | BTU fuel oil | 1032 | |

| | | | |
|---|---|---|---|
| cu. ft NG | BTU NG | 12000 | Chemical Engineers' Handbook, 6th ed. |
| lb Coal (dry) | BTU Coal | 46 | calculation page B SD=11% |
| kg NG | MJ NG | | Calculated page C SD=13% |

Calculations

Ethylene Production

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|---|
| | 1 Kg | | | | | | | |
| soda caustic (polymer) | | | | | 3 | | | |
| soda caustic (other) | | | | | | | | |
| | | | | | | | 0 | |

SimaPro3
Average data for 19 european cracking fascilities producing monomer quality soda caustic.
taken from:
PWMI/APME, Ecoprofiles of the European plastics industry, 1992-1994
report 2, tbl 36 pg 21

Energy input

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|---|
| | MJ/Kg soda caus | | | | | | | |
| Coal | MJ/Kg soda caus | 5.86 | | | 3 | Kg/Kg soda caustic | 0.217294119 | |
| Oil | MJ/Kg soda caus | 3.5 | | | 3 | Kg/Kg soda caustic | 0.129783177 | |
| Natural Gas | MJ/Kg soda caus | 4.76 | | | 3 | Kg/Kg soda caustic | 0.176505121 | |
| Hydropower | MJ/Kg soda caus | 0.71 | | | 3 | MJ/Kg soda caustic | 0.734851726 | |
| Fission | MJ/Kg soda caus | 5.74 | | | 3 | MJ/Kg soda caustic | 5.940913952 | |
| unspecified | | 0.72 | | | | | | |

Probably different mix in US

Material input

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|---|
| | MJ/Kg soda caus | | | | | | | |
| Oil | MJ/Kg soda caus | 0 | | | 3 | Kg/Kg soda caustic | 0 | |
| Natural Gas | MJ/Kg soda caus | 0 | | | 3 | Kg/Kg soda caustic | 0 | |
| Coal | Kg/Kg soda caus | 0 | | | 3 | Kg/Kg soda caustic | 0 | |
| Iron ore | Kg/Kg soda caus | 0.00046 | | | 3 | Kg/Kg soda caustic | 0.00046 | |
| limestone | Kg/Kg soda caus | 0.0105 | | | 3 | Kg/Kg soda caustic | 0.0105 | |
| Bauxite | Kg/Kg soda caus | 0 | | | 3 | Kg/Kg soda caustic | 0 | |
| Rock salt | Kg/Kg soda caus | 0.59 | | | 3 | Kg/Kg soda caustic | 0.59 | |
| Clay | Kg/Kg soda caus | 0 | | | 3 | Kg/Kg soda caustic | 0 | |
| Water | Kg/Kg soda caus | 5.3 | | | 3 | Kg/Kg soda caustic | 5.3 | |
| sand | | 0.00002 | | | 3 | Kg/Kg soda caustic | 0.00002 | |

Output

| Air | Raw/ Input Units | Raw/ | Raw/ | | | Transformed | Transformed | Transformed |
|---|---|---|---|---|---|---|---|---|

| LCI component | Kg/Kg soda caus | Input Quan. | Input Std. Dev. | DQI | Units | Quan. | Std. Dev. |
|---|---|---|---|---|---|---|---|
| TSP | Kg/Kg soda caus | 0.074 | | | Kg/Kg soda caustic | 0.074 | |
| SOx | Kg/Kg soda caus | 0.00002 | | | Kg/Kg soda caustic | 0.00002 | |
| NOx | Kg/Kg soda caus | 0.007 | | | Kg/Kg soda caustic | 0.007 | |
| CO | Kg/Kg soda caus | 0.0008 | | | Kg/Kg soda caustic | 0.0008 | |
| CO2 | Kg/Kg soda caus | 1.21 | | | Kg/Kg soda caustic | 1.21 | |
| H2S | Kg/Kg soda caus | 0 | | | Kg/Kg soda caustic | 0 | |
| HCl | Kg/Kg soda caus | 0.00018 | | | Kg/Kg soda caustic | 0.00018 | |
| total HC's | | 0.006 | | | Kg/Kg soda caustic | 0.006 | |
| | Kg/Kg soda caustic | | | | | | |
| Heavy metals | | 0.000002 | | | Kg/Kg soda caustic | 0.000002 | |

Water

| LCI component | Raw/ Input Units Kg/Kg soda caus | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| COD | Kg/Kg soda caus | 0.00001 | | | Kg/Kg soda caustic | 0.00001 | |
| BOD | Kg/Kg soda caus | 0.000003 | | | Kg/Kg soda caustic | 0.000003 | |
| Acid as H+ | Kg/Kg soda caus | 0.00034 | | | Kg/Kg soda caustic | 0.00034 | |
| Nitrate | Kg/Kg soda caus | 0 | | | Kg/Kg soda caustic | 0 | |
| Metal ions | Kg/Kg soda caus | 0.00009 | | | Kg/Kg soda caustic | 0.00009 | |
| Cl2 | Kg/Kg soda caus | 0.042 | | | Kg/Kg soda caustic | 0.042 | |
| ammonia | Kg/Kg soda caus | 0 | | | Kg/Kg soda caustic | 0 | |
| dissolved organics | Kg/Kg soda caus | 0 | | | Kg/Kg soda caustic | 0 | |
| suspended particles | Kg/Kg soda caus | 0.002 | | | Kg/Kg soda caustic | 0.002 | |
| Crude | Kg/Kg soda caus | 0 | | | Kg/Kg soda caustic | 0 | |
| dissolved substances | Kg/Kg soda caus | 0.00005 | | | Kg/Kg soda caustic | 0.00005 | |
| HC's | Kg/Kg soda caus | 0 | | | Kg/Kg soda caustic | 0 | |
| sodium | | 0.0028 | | | Kg/Kg soda caustic | 0.0028 | |
| Solid waste | Kg/Kg soda caus | | | | | | |
| Production waste (not innert) | Kg/Kg soda caus | 0.099 | | | Kg/Kg soda caustic | 0.099 | |
| Toxic chemicals | | 0.00002 | | | Kg/Kg soda caustic | 0.000001 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1000 bbl/day | | | | | | |
| CrO from Alaska | | 1798 | | | ton/yr | 99228024 | |
| Total | | | | | ton/yr | 99228024 | |
| | mi | | | | | | |
| Water Shipping - Lower 48 | mi | 0 | | | ton-mi/yr | 0 | |
| Water Shipping - Alaska | | 2439.6 | | | ton-mi/yr | 2.42077E+11 | |

Crude Oil Transport

Association of Oil Pipe Lines Data for 1990

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| | mi | | | | | | |
| Pipelines | mi | 0 | | | | | |
| Water | mi | 2439.6 | | | | | |
| Highway/Motor Carrier | mi | 1000 | | | | | |
| Rail | | 697 | | | | | |

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| | BTU/ton-mi | | | | | | |
| Pipelines | BTU/ton-mi | 0 | | | | | |
| Water | BTU/ton-mi | 361 | | | gal fuel/bbl CrO | 0.964936049 | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Highway/Motor Carrier | BTU/ton-mi | 434 | | gal fuel/bbl CrO | 0.553762025 | |
| Rail | | 434 | | gal fuel/bbl CrO | 0.385972132 | |

Water Transport Emissions

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| | lb/1000 gal fuel | | | | | | |
| SOx | lb/1000 gal fuel | 27 | | | kg/bbl CrO | 0.011817566 | |
| CO | lb/1000 gal fuel | 100 | | | kg/bbl CrO | 0.043768763 | |
| HC | lb/1000 gal fuel | 50 | | | kg/bbl CrO | 0.021884382 | |
| NOx | lb/1000 gal hauled | 280 | | | kg/bbl CrO | 0.122552537 | |
| HC - transfer | | 0.97 | | | kg/bbl CrO | 0.018479353 | |

Highway Transport Emissions

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| | lb/1000 gal fuel | | | | | | |
| HC | lb/1000 gal fuel | 5.4572 | | | kg/bbl CrO | 0.001370752 | |
| CO | lb/1000 gal fuel | 15.3321 | | | kg/bbl CrO | 0.003851151 | |
| NOx | lb/1000 gal hauled | 18.6622 | | | kg/bbl CrO | 0.004687613 | |
| HC - transfer | | 3.25 | | | kg/bbl CrO | 0.061915359 | |

Railroad Transport Emissions

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| | lb/1000 gal fuel | | | | | | |
| TSP | lb/1000 gal fuel | 25 | | | kg/bbl CrO | 0.00437685 | |
| SOx | lb/1000 gal fuel | 57 | | | kg/bbl CrO | 0.009979219 | |
| CO | lb/1000 gal fuel | 130 | | | kg/bbl CrO | 0.022759622 | |
| HC | lb/1000 gal fuel | 94 | | | kg/bbl CrO | 0.016456957 | |
| NOx | lb/1000 gal fuel | 370 | | | kg/bbl CrO | 0.064777386 | |
| Aldehydes | lb/1000 gal fuel | 5.5 | | | kg/bbl CrO | 0.000962907 | |
| Organic Acids | lb/1000 gal hauled | 7 | | | kg/bbl CrO | 0.001225518 | |
| HC - transfer | ============ | 3.25 | | | kg/bbl CrO | 0.061915359 | |

Sheet End ========= ============ =========== =========== =========== =============== =========== =========== ========= ========= =========

**Sheet Title:** Sulfuric Acid (for phosphate wet method production)

**Sheet Description:** This page calculates the vendor-independent emissions from domestic production of sulfuric acid. Oil extraction and transportation are not included

**References/Citations:** U.S. EPA. 1995. AP-42, Fifth Edition, Table 8.8-1.

The Fertilizer Institute. 1982. The Fertilizer Handbook

**Summary Output**

Co-product Allocation Calculations

| Co-product | Quantity | Units |
|---|---|---|
| H2S04 | 1.00E+00 | Kg |
| Total | 1 | kg |

Notes: Bbl eq. are calculated on a energy content basis and used to calcualte the allocated LCI emissions factors. Bbl. of CrO production are scaled by multiplying by the ratio of bbl eq. CrO produced to bbl CrO produced.

| LCI components | Unallocated Units | Quantity | Std. Dev. | Allocated Units | Quantity | Std. Dev. | DQI |
|---|---|---|---|---|---|---|---|
| Air | | | | | | | |
| SOx | Kg/Kg Sulfuric | 0.013 | | | | | 4 |
| CO2 | Kg/Kg Sulfuric | 0.00405 | | | | | 4 |
| H2SO4 | Kg/Kg Sulfuric | 0.000064 | | | | | 4 |
| Water | | | | | | | |
| Solid Wastes | | | | | | | |
| Resource Consumption | | | | | | | |

Notes: This section is where the project specfic calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Process Emissions from Sulfuric Acid Manufacture (data for phosphoric acid manufacture, applied to general use: HNO3, ion exchange etc.)

(1) U.S. EPA. 1995. AP-42, Fifth Edition, Table 8.8-1.

(2) The Fertilizer Institute. 1982. The Fertilizer Handbook

Sulfuric acid is used in the manufacture of many precursors to TNAZ. Emission consist primarily of sulfur dioxide and acid mist. Sulfur dioxide emissions are primarily a function of the conversion efficiency from SO2 to SO3 in the plant.

Emission Factors

**Conversion Factors**

| Unit from | Unit to | Multiplier | Name | Source: | |
|---|---|---|---|---|---|
| bu | lb | 56 | lb_bu | | |
| Hectares | acre | 2.471 | acre_hect | | |
| kg | lb | 2.2046 | lb_kg | | |
| hectares | sq. meters | 10,000 | sqmeters_hect | | |
| meter | feet | 3.281 | feet_meter | | |
| short tons | lb | 2000 | lb_shortton | | |
| metric tons | kg | 1000 | kg_mton | | |
| kcal | btu | 3.968 | btu_kcal | | |
| Joules | btu | 9.49E-04 | btu_joule | | |
| Gallons Etha | lb | 6.6 | lb_gallon | | |
| Gallons Etha | bu | 0.4 | bu_gallon | | |
| Hectares | Sq. cm | 1.00E+08 | sqcm_ha | | |
| cubic cm | liters | 0.001 | liters_ccm | | |
| liters | gallons | 0.264 | gallons_liter | | |
| sq mile | acres | 640 | acres_sqmile | | |
| metric tons | short tons | 1.102 | shortton_metricton | | |
| barrels | gallons | 42 | gallons_barre | 0 | |
| kg | grams | 1,000 | grams_kg | | |
| cubic foot na | btu | 1,032 | btu_cubicft | 0 | |
| barrel distilla | million btu | 5.825 | btu_barreloil | 0 | 138,690 |
| barrel motor | million btu | 5.253 | btu_barrelga | 0 | 125,071 |
| Short ton coa | million btu | 22.25 | Btu_toncoal | 0 | |
| Barrel LPG | million btu | 3.614 | Btu_barrellpg | | 86,048 |

Molecular Wts.

| | |
|---|---|
| H | 1.008 |
| O | 16.00 |
| Cl | 35.45 |
| K | 39.10 |
| CO2 | #REF! |
| CaSO4 | #REF! |

| Conversion Eff. - $SO_2$ -> $SO_3$ | $SO_2$ Emissions lb/ton sulfuric | Kg/Kg Sulfuric acid | |
|---|---|---|---|
| 93 | 96 | 0.048 | |
| 94 | 82 | 0.041 | |
| 95 | 70 | 0.035 | |
| 96 | 55 | 0.0275 | |
| 97 | 40 | 0.02 | |
| 98 | 26 | 0.013 | <=taken as representative |
| 99 | 14 | 0.007 | |
| 99.5 | 7 | 0.0035 | |
| 99.7 | 4 | 0.002 | |
| 100 | 0 | 0 | |

Notes: Sulfur dioxide emissions are highly correlated with conversion efficiency. Typical conversion efficiencies are given in AP-42 as 95 to 98%. Sufur emissions can be controlled using standard sulfur capture technologies. New Source Performance Standards are also set quite low, at 4 lb/ton of product. Assuming that new plants comply with NSPS limits, but that old plants exist with higher emissions, the emission rate used here is at the upper end of conversion efficiency estimates.

Acid Mist Emission Factors (Where values are given as a range, the midrange is used)

| | lb/ton $H_2SO_4$ | | kg/Kg Sulfuric acid | | |
|---|---|---|---|---|---|
| Raw Material | Uncontrolled | Controlled | Uncontrolled | Controlled | |
| Recovered Sulfur | 0.574 | - | 0.000287 | | |
| Elemental Sulfur | - | 0.128 | | 0.000064 | <=taken as representative |
| Bright Virgin Sulfur | 1.7 | - | 0.00085 | | |
| Dark Virgin Sulfur | 3.3 | 2.06 | 0.00165 | 0.00103 | |
| Spent Acid | 2.3 | 0.34 | 0.00115 | 0.00017 | |

Notes: According to AP-42 about 81% of sulfuric acid production is from elemental sulfur buming. Average emission factors are calculated above using the elemental, bright virgin, and dark virgin sulfur factors. The uncontrolled and controlled factors are then averaged.

| | | |
|---|---|---|
| Carbon Dioxide | 8.1 | lb/ton sulfuric acid |
| | 0.00405 | Kg/Kg Sulfuric acid |

Notes: Carbon dioxide emissions are negligible relative to other sources and are thus neglected.

Sheet Title: Chlorobenzenes (mono- for triphenyl posphine production)

Sheet Description: Emissions are from TRI database.
Engineering calculation (rough) of the Energy requirements based on the cooling and distillation needs.
This page calculates the vendor emissions from a plant producing Chlorobenzenes.
Not included are raw material production or extraction or water and energy use.

References/Citations:

Faith Keyes and Clarke's Industrial Chemicals
By F. A. Lowenheim, M. K. Moran
Wiley Interscience, 1975

Perry's Chemical Engineers' Handbook, 6th ed.
McGraw Hill, 1984

AP 42 Ed 4 (1985)
US EPA

Kirk Othmer Encyclopaedia of Chemical Technology
2nd ED, 1964 and 4th Ed, 1991-4
Wiley Interscience,

US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993
US International Trade Commission, 11.1994

CRC Handbook of Chemistry and Physics, 66th Edition

Summary Output ------------------------------------------------------------

Co-product Allocation Calculations

Source: US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993
US International Trade Commission, 11.1994

| Mwt | Co-product | Quantity | Units | Quantity | Units | |
|---|---|---|---|---|---|---|
| 112.559 | Chlorobenzene | 8.85E+07 | kg | 1.72E+00 | kg | |
| | Not as precursor: | 5.15E+07 | kg | 1.00E+00 | kg | |
| 147.091 | o-dichlorobenzen | 15767000 | kg | 3.06E-01 | kg | derivative of mono-chlorobenzene |

| | | | | | | |
|---|---|---|---|---|---|---|
| 147.091 | p-dichlorobenzen | 32614000 | kg | 6.34E-01 | kg | derivative of mono-chlorobenzene |
| | trichlorobenzenes | | kg | | kg | |
| 36.4609 | HCl | 40660216.8 | kg | 7.90E-01 | Kg | Product of chlorination |
| | Total | 1.41E+08 | Kg | 2.73E+00 | Kg | |

Notes:

| LCI components | Unallocated Units | Quantity | Std. Dev. | Allocated Units | Quantity | Std. Dev. | DQI |
|---|---|---|---|---|---|---|---|
| Air | | | | | | | |
| Cl2 | Kg/Kg Chlorob | 0.004199242 | | Kg/Kg Chlorob | 0.002442546 | | 3 |
| Benzene | Kg/Kg Chlorob | 5.32399E-06 | | Kg/Kg Chlorob | 3.09677E-06 | | 3 |
| HCl | Kg/Kg Chlorob | 0.0072757 | | Kg/Kg Chlorob | 0.004232035 | | 3 |
| dichlorobenzenes | Kg/Kg Chlorob | 4.31031E-06 | | Kg/Kg Chlorob | 2.50715E-06 | | 3 |
| chlorobenzene | Kg/Kg Chlorob | 7.01061E-05 | | Kg/Kg Chlorob | 4.07782E-05 | | 3 |
| Water | | | | | | | |
| Solid Wastes | | | | | | | |
| Resource Consumption | | | | | | | |
| Heat Energy (fos | MJ/Kg Chlorob | 4.396342073 | | MJ/Kg Chlorob | 4.396342073 | | |
| Electric Power | MJ/Kg Chlorob | 2.361E-05 | | MJ/Kg Chlorob | 2.361E-05 | | |
| Benzene | Kg/Kg Chlorob | 0.693971215 | | Kg/Kg Chlorob | 0.693971215 | | |
| Chlorine | Kg/Kg Chlorob | 0.629886283 | | Kg/Kg Chlorob | 0.629886283 | | |
| Sodium hydroxid | Kg/Kg Chlorob | 0.008664743 | | Kg/Kg Chlorob | 0.008664743 | | |

Notes: This section is where the project specfic calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors

| Unit from | Unit to | Multiplier | Reference |
|---|---|---|---|
| BTU | J | 1055.056 | CRC, 66th Edition |
| Wh | J | 3600 | CRC, 66th Edition |

| | | | | |
|---|---|---|---|---|
| bbl CrO | BTU CrO | 5800000 | Chemical Engineers' Handbook, 6th ed. | |
| bbl | gal | 42 | Chemical Engineers' Handbook, 6th ed. | |
| gal diesel | BTU diesel | 118500 | Chemical Engineers' Handbook, 6th ed., Figure 9-4 @ S.G. = .76 and sulfur = 0.5% | |
| gal | L | 3.785412 | CRC, 66th Edition | |
| kg | lb | 2.2046226 | CRC, 66th Edition | |
| yr | day | 365 | | |
| m^3 | bbl (petroleum) | 6.289811 | CRC, 66th Edition | |
| gal CrO | lb CrO | 7.2 | | |
| ton | lb | 2000 | | |
| gal fuel oil | BTU fuel oil | 138000 | | |
| cu. ft NG | BTU NG | 1032 | Chemical Engineers' Handbook, 6th ed. | |
| lb Coal (dry | BTU Coal | 12000 | calculation page B | SD=11% |
| kg NG | MJ NG | 46 | Calculated page C | SD=13% |

| | |
|---|---|
| Mw Benzen | 78.1134 |
| Mw Chlorin | 70.9 |
| Mw ClBz | 112.56 |
| Mw Cl2Bz | 147.01 |
| Mw HCl | 36.4609 |
| Mw NaOH | 39.9971 |

| molar dry air composition | | Mwt | mass composition | kg air per kg component |
|---|---|---|---|---|
| N2 | 0.78084 | 28.0134 | 0.75521 | 1.324134 |
| O2 | 0.20946 | 31.9988 | 0.231406 | 4.321406 |
| CO2 | 0.00033 | 44.01 | 0.000501 | 1994.319 |
| Ar | 0.00934 | 39.948 | 0.012882 | 77.62792 |
| total | 0.99997 | 28.96409 | 1 | |

Ideal gas density at 15 C (60 F) — air (dry)

0.042296 mol/liter — 42.29634021 mol/m^3 — 1.225075005 kg/m^3

Calculations

Chlorobenzene Production

Energy input

All energy is assumed to come from the heat of combustion in the formation of CO, which is recoverable.

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| Fossil fuel (general) | MJ/kg Chlorobe | 4.396342073 | | | | 0.157507219 | |
| Coal | MJ/kg Chlorobe | 0 | | | kg/kg Chlorobenze | 0 | |
| Oil | MJ/kg Chlorobe | 0 | 15 | | kg/kg Chlorobenze | 0 | 0.33622909 |
| Natural Gas | MJ/kg Chlorobe | 0 | | | kg/kg Chlorobenze | 0 | |
| Hydropower | MJ/kg Chlorobe | 0 | | | | | |
| Fission | MJ/kg Chlorobe | 0 | | | | | |

| | | | | |
|---|---|---|---|---|
| Electricity (generic) | MJ/kg Chlorobe | 2.361E-05 | | |
| | | | | Probably different mix in US |

Material input

Source: Faith Keyes and Clarke's Industrial Chemicals
By F. A. Lowenheim, M. K. Moran
Wiley Interscience, 1975

Benzene batch Chlorination method ($Cl_2$ bubbled through)

from Faith Keyes and Clark's Industrial chemicals, 1975

| Stoichiometric ratios: | | | | |
|---|---|---|---|---|
| Benzene net | Kg/Kg Chlorob | 0.693971215 | 100% | conversion of Benzene |
| Cl2 net | Kg/Kg Chlorob | 0.629886283 | | |
| Benzene input | Kg/Kg Chlorob | 0.693971215 | 100% | conversion of Benzene |
| Cl2 input - no recycle | Kg/Kg Chlorob | 1.049810471 | 60% | conversion of Cl2 |
| Chlorine input | Kg/Kg Chlorob | 0.634085525 | 99% | Cl2 recovery - assumed, because of bubbling apparatus |

Emission calculation

| Air | | | | |
|---|---|---|---|---|
| Cl2 released from process | Kg/Kg Chlorob | 0.004199242 | 1% | Uncoverted Cl2 |
| HCl released | Kg/Kg Chlorob | 0.0072757 | | released in scrubber vent see calculation |
| CO2 | Kg/Kg Chlorob | 0 | | |
| Particulates | Kg/Kg Chlorob | 0 | | |
| Benzene | Kg/Kg Chlorob | 5.32399E-06 | | open neutralizer vent |
| mono Chlorobenzene | Kg/Kg Chlorob | 7.01061E-05 | | |
| o dichlorobenzene | Kg/Kg Chlorob | 4.31031E-06 | | |
| p dichlorobenzene | Kg/Kg Chlorob | 0 | | |
| SOx | Kg/Kg Chlorob | 0 | | |
| NOx | Kg/Kg Chlorob | 0 | | |
| Heavy metals | Kg/Kg Chlorob | 0 | | |

**HCl emission calculation**

Vapor pressure of 1mmHg over water solution 20%

Open scrubber assumed to equilibrate so that vapor containing 1/760 parts volume HCl is displaced from the scrubbing chamber by the incoming water/HCl stream 20% HCl

7.90E-01 Kg HCl produced/Kg Chlorobenzene

| | | | | |
|---|---|---|---|---|
| HCl sol. density kg/m^3(roug | 1100 | | 3.949340383 | Kg HCl stream |
| HCl partial pressure mmHg | 1 | CRC 66 | 0.0072757 | Kg HCl (1/760) |
| Overall pressure (atm) mmH | 761 | CRC 66 | | |

**Benzene Emissions calculation**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Vapor pressure at condenser vent assumed to be at 25 degC | | | | | | | | Raoult's law | Kg emission/Kg prod |
| Composition (mol%) | | | | wt% | | | | vapor composition | |
| Bz 99% con | 78.11 | 0.01 | 0.781134 | 0.006315964 | Bz | 100 | mmHg | 0.00131406 | 5.32E-06 |
| ClBz | 112.56 | 0.7 | 78.792 | 0.637083303 | ClBz | 13.05454545 | mmHg | 0.012008123 | 7.01E-05 |
| Cl2Bz-o | 147.01 | 0.2 | 29.402 | 0.237733822 | Cl2Bz-o | 2.150895141 | mmHg | 0.000565281 | 4.31E-06 |
| Cl2Bz-p | 147.01 | 0.1 | 14.701 | 0.118866911 | Cl2Bz-p solid a | 0 | mmHg | 0 | 0 |
| Source: FKC 75 4ed | | | 123.676134 | | CRC 66 interpolated | | | | |

| | | | | |
|---|---|---|---|---|
| vapor displacement by chlorobenzine product/kg mono ClB | 0.00122629 | m^3 | 0.051867653 | mol gas displaced/kg ClBz |
| density of ClBz at end of react | 1,280.00 | kg/m^3 | | |

Co-Products:
source: See from above

Resources:

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| Oil | | | | | Kg/Kg Chlorobenzene | | |
| Natural Gas | | | | | Kg/Kg Chlorobenzene | | |
| Coal | Kg/Kg Chlorob | 0 | | 3 | Kg/Kg Chlorobenz | 0 | |
| Iron ore | Kg/Kg Chlorob | 0 | | | Kg/Kg Chlorobenz | 0 | |
| Benzene | Kg/Kg Chlorob | 0.693971215 | | 3 | Kg/Kg Chlorobenz | 0.693971215 | |
| Chlorine | Kg/Kg Chlorob | 0.629886283 | | | Kg/Kg Chlorobenz | 0.629886283 | |
| Sodium hydroxide (dry bassi | Kg/Kg Chlorob | 0.008664743 | | | Kg/Kg Chlorobenz | 0.008664743 | |
| Clay | Kg/Kg Chlorob | 0 | | | Kg/Kg Chlorobenz | 0 | |

Water

| | Raw/ | Raw/ | Raw/ | | Transformed | Transformed | Transformed |
|---|---|---|---|---|---|---|---|

| LCI component | Input Units | Input Quan. | Input Std. Dev. | DQI | Units | Quan. | Std. Dev. |
|---|---|---|---|---|---|---|---|
| COD | Kg/Kg Chlorob | 0 | | | Kg/Kg Chlorobenz | 0 | |
| BOD | Kg/Kg Chlorob | 0 | | | Kg/Kg Chlorobenz | 0 | |
| Acid as H+ | Kg/Kg Chlorob | 0 | | | Kg/Kg Chlorobenz | 0 | |
| Metal ions | Kg/Kg Chlorob | 0 | | | Kg/Kg Chlorobenz | 0 | |
| Cl2 | Kg/Kg Chlorob | 0 | | | Kg/Kg Chlorobenz | 0 | |
| Dissolved Organics | Kg/Kg Chlorob | 0 | | | Kg/Kg Chlorobenz | 0 | |
| suspended solids | Kg/Kg Chlorob | 0 | | | Kg/Kg Chlorobenz | 0 | |
| crude oil | Kg/Kg Chlorob | 0 | | | Kg/Kg Chlorobenz | 0 | |
| miscelanious dissolved mate | Kg/Kg Chlorob | 0 | | | Kg/Kg Chlorobenz | 0 | |
| Phenol | Kg/Kg Chlorob | 0 | | | Kg/Kg Chlorobenz | 0 | |

Solid waste ------------------ ------------------ ------------------ ---------------------- ------------------ ------------------

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| Production waste (not innert) | Kg/Kg Chlorob | 0 | | | Kg/Kg Chlorobenz | 0.00128 | |
| Toxic chemicals | Kg/Kg Chlorob | 0 | | | Kg/Kg Chlorobenz | 0.000001 | |
| Ash | Kg/Kg Chlorob | 0 | | | | | |

Sheet End ======== =========== =========== =========== =========== =========== ============= =========== =========== ======== ======== ========

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1993 | | | | | | | | | | | | | | | | | | |
| 8.85E+07 | | kg | mono chlorobenzene | | | | | | | | | | | | | | | |
| 48381000 | | kg | dichlorobenzenes | | | | | | | | | | | | | | | |
| Capacities | production | | | | DHfo | DHrx (synthesis) | | | Refrigeration | water flow | | pump for co | material pun | Distillation | | pump for co | Elec total | Heat total |
| Mlb | | | | | kcal/mol | kcal/mol | kJoules/kg prod | | Heat consump | m^3/kg prod | | kJ Elec/Kg p | kJ Elec/Kg p | kJ/kg prod | m^3/kg prod | kJ Elec/Kg p | kJ Elec/Kg p | kJ/kg prod |
| | | | | | | | | | kJ/kg prod | | | | | | | | | |
| 50 | 15767000 | o | dichlorobenzenes | | 39.995 | -13.839 | -393.5171 | from mono | 605.410989 | 0.1649158 | 1011.6387 | 0.0129832 | 0.0005511 | | | | | |
| 75 | 32614000 | p | dichlorobenzenes | | 39.995 | -13.839 | -393.5171 | from mono | 605.410989 | 0.1649158 | 2092.572 | 0.0129832 | 0.0005511 | | | | | |
| 150 | 8.85E+07 | mono | mono chlorobenzene | | 13.882 | -13.839 | -513.9216 | from benzen | 790.64868 | 0.2153751 | 7415.7123 | 0.0169556 | 0.0005511 | 3605.6934 | 0.0775256 | 0.0061033 | 0.02361 | 4396.3421 |
| | | | HCl | | -39.952 | | | | 65% efficiency | | | | | | | | | |
| | | | Benzene | | -12.231 | | | | | | | | 7 pumping stages per material | | | | | |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 42.8 | Btu/ton*min | | | | | |
| | | | | | | | | | 45.15828 | kJ/ton*min | | | | | |
| | | | | | | | | water requir | 3.25 | gal water/ton*min | | 0.078726 | kJ Elec/m^3 | | |
| | | | | | | | | | 0.0002724 | m^3/kJ | | 7.873E-05 | kJ Elec/Kg | | |
| | | | | | | | | | 250 | ft representative head value | | | | cooling value of water | |
| | | | separations | | | | | | 65% | heat removal efficiency | | | | 19.99683 | Btu/lb |
| | | | Distill mono from 75% to 100% with 10% heavy, 10% light | | | | | | 150/371 | production factor for plant | | | | 46.509688 | kJ/kg |
| | | | | | | | | | 40 hr week | | | | | | |
| | | | minimum energy | | | | | | 52 week year | | | | | | |
| | | | 10% of vaporization heat * recycle | | | | | | 77.50% | pump efficiency | | | | | |
| | | | | | | DHvap | KJ/Kg | btu/lb | KJ/Kg | | | | | | |
| | | | Heat | 126.3 | Btu req | cal/mol | | 1403.3333 | 3263.94704 | both | | | | | |
| | | | Cool | 118.9 | Btu req | | | 4210 | 9791.84113 | light | | | | | |
| | 92.15 | 110.6 | | 0.06 | toluene | 9368.5 | 425.65576 | | 12.3968043 | | | | | | |
| | 78.54 | 80.1 | Medium/Eas | 0.03 | benzene | 10254 | 548.73537 | | | | | | | | |
| | | | | 0.01 | waste | ? | | | | | | | | | |
| | | | Heat | 405.9 | Btu req | cal/mol | | 162.36 | 377.625493 | both | | | | | |
| | | | Cool | 260.1 | Btu req | | | 4059 | 9440.63733 | light | | | | | |
| | 104.16 | 145.2 | | 2.4 | styrene | 9634.7 | 437.7505 | | 1.99812103 | | | | | | |
| | 87.613333 | 100.43333 | | 0.1 | Bz&tol | 9301.3 | 497.75232 | | | | | | | | |
| | | | | 0.01 | waste | ? | | | | | | | | | |
| | | | Heat | 1308.2 | Btu req | cal/mol | | 551.98312 | 1283.8316 | both | | | | | |
| | | | Cool | 1318.9 | Btu req | | | 998.62595 | 2322.65717 | light | | | | | |
| | 104.16 | 145.2 | | 1.06 | styrene | 9634.7 | 437.7505 | | 18.0344903 | | | | | | |
| | 106.17 | 136.2 | | 1.31 | ethylBz | 9301.3 | 497.75232 | | | | | | | | |
| | | | | 0.01 | waste | ? | | | | | | | | | |
| | | | Heat | 1023.1763 | Btu req | | | | | | | | | | |
| | | | Cool | 1318.9 | Btu req | | | 1162.7003 | 2704.27004 | 3605.6934 | | | | | |
| | 147.01 | 180.5 | | 0.12 | Cl2Bz-o | 10098 | 458.80043 | | 4 | | | | | | |
| | 112.56 | 132 | 17611 | 0.88 | ClBz | 10943 | 497.19283 | | | | | | | | |
| | 147.01 | 174 | | | Cl2Bz-p | 10611 | | | | | | | | | |
| | 147.01 | 173 | | | Cl2Bz-m | | | | | | | | | | |

Sheet Title: benzene (for chemical and styrene monomer production)

Sheet Description: This page calculates the vendor-independent emissions from european refineries producing technical quality benzene
Included are oil extraction and transportation from the well head to the refinery.

References/Citations: SimaPro3 (entry of Nov 18 94)
Average data for 19 european cracking fascilities producing monomer quality ethylene.
taken from:
PWMI/APME, Ecoprofiles of the European plastics industry, 1992-1994
report 4, tbl 12 pg 10

Summary Output

Co-product Allocation Calculations

| Co-product | Quantity | Units |
|---|---|---|
| benzene | 1.00E+00 | Kg |
| Total | 1 | Kg |

| LCI components | Unallocated Units | Quantity | Std. Dev. | Allocated Units | Quantity | Std. Dev. | DQI |
|---|---|---|---|---|---|---|---|
| Air | | | | | | | |
| COD | Kg/Kg benzene | 0.0009 | | | | | 3 |
| BOD | Kg/Kg benzene | 0.003 | | | | | 3 |
| Acid as H+ | Kg/Kg benzene | 0.0068 | | | | | 3 |
| Nitrate | Kg/Kg benzene | 0.0006 | | | | | 3 |
| Metal ions | Kg/Kg benzene | 0.54 | | | | | 3 |
| Cl2 | Kg/Kg benzene | 0.000005 | | | | | 3 |
| ammonia | Kg/Kg benzene | 0.00015 | | | | | 3 |
| dissolved organi | Kg/Kg benzene | 0.0083 | | | | | 3 |
| Crude | Kg/Kg benzene | 0.000001 | | | | | 3 |
| dissolved substa | Kg/Kg benzene | 0.00054 | | | | | |
| HC's | Kg/Kg benzene | 0.00008 | | | | | |
| unknown (N) | Kg/Kg benzene | 0.000001 | | | | | |
| Water | | | | | | | |
| COD | Kg/Kg benzene | 0.0002 | | | | | 3 |
| BOD | Kg/Kg benzene | 0.00002 | | | | | 3 |
| Acid as H+ | Kg/Kg benzene | 0.00004 | | | | | 3 |
| Metal ions | Kg/Kg benzene | 0.00036 | | | | | 3 |

| | | | | | |
|---|---|---|---|---|---|
| | Cl2 | Kg/Kg benzene | 0.00009 | | 3 |
| | Dissolved Organ | Kg/Kg benzene | 0.000015 | | 3 |
| | suspended solid | Kg/Kg benzene | 0.00012 | | 3 |
| | crude oil | Kg/Kg benzene | 0.0001 | | 3 |
| | miscelanious dis | Kg/Kg benzene | 0.00054 | | 3 |
| | total HC's | Kg/Kg benzene | 0.00008 | | |
| | Phenol | Kg/Kg benzene | 0.000001 | | 3 |
| | Solid Wastes | | | | |
| | Production waste | Kg/Kg benzene | 0.00966 | | 3 |
| Resource Consumption | | | | | |
| | Natural Gas | Kg/Kg benzene | 0.786521739 | 30150000 | 3 |
| fuel | Natural Gas | Kg/Kg benzene | 0.159347826 | 6108333.333 | #VALUE! |
| | Crude Oil | Kg/Kg benzene | 0.624041192 | 111.0362948 | #VALUE! |
| fuel | Crude Oil | Kg/Kg benzene | 0.031605534 | 5.623605447 | #VALUE! |
| | Coal | Kg/Kg benzene | 0.000358269 | | |
| fuel | Coal | Kg/Kg benzene | 0.022929203 | 4.079816828 | 3 |
| | Hydropower | MJ/Kg benzene | 0.07 | | |
| | Fission | MJ/Kg benzene | 0.2 | | |
| | Iron ore | Kg/Kg benzene | 0.00015 | | |
| | limestone | Kg/Kg benzene | 0.00011 | | |
| | Bauxite | Kg/Kg benzene | 0.00022 | | |
| | Rock salt | Kg/Kg benzene | 0.0058 | | |
| | Clay | Kg/Kg benzene | 0.00002 | | |
| | Water | Kg/Kg benzene | 2.209 | | |

Notes: This section is where the project specfic calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors

| Unit from | Unit to | Multiplier | Reference |
|---|---|---|---|
| BTU | J | 1055.056 | CRC, 66th Edition |
| Wh | J | 3600 | CRC, 66th Edition |
| bbl CrO | BTU CrO | 5800000 | Chemical Engineers' Handbook, 6th ed. |
| bbl | gal | 42 | Chemical Engineers' Handbook, 6th ed. |
| gal diesel | BTU diesel | 118500 | Chemical Engineers' Handbook, 6th ed., Figure 9-4 @ S.G. = .76 and sulfur = 0.5% |
| gal | L | 3.785412 | CRC, 66th Edition |
| kg | lb | 2.2046226 | CRC, 66th Edition |
| yr | day | 365 | |
| m^3 | bbl (petroleum) | 6.289811 | CRC, 66th Edition |

| | | | | |
|---|---|---|---|---|
| gal CrO | lb CrO | 7.2 | | |
| ton | lb | 2000 | | |
| gal fuel oil | BTU fuel oil | 138000 | | |
| cu. ft NG | BTU NG | 1032 | Chemical Engineers' Handbook, 6th ed. | |
| lb Coal (dry) | BTU Coal | 12000 | calculation page B | SD=11% |
| kg NG | MJ NG | 46 | Calculated page C | SD=13% |

Calculations

Ethylene Production

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| benzene (polymer) | 1 Kg | | | 3 | | | |
| benzene (other) | | | | | | | |
| | | | | | | 0 | |

SimaPro3
Average data for 19 european cracking fascilities producing monomer quality benzene.
taken from:
PWMI/APME, Ecoprofiles of the European plastics industry, 1992-1994
report 2, tbl 36 pg 21

Energy input

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| Coal | MJ/Kg benzene | 0.64 | | 3 | Kg/Kg benzene | 0.022929203 | |
| Oil | MJ/Kg benzene | 1.41 | | 3 | Kg/Kg benzene | 0.031605534 | |
| Natural Gas | MJ/Kg benzene | 7.33 | | 3 | Kg/Kg benzene | 0.159347826 | |
| Hydropower | MJ/Kg benzene | 0.07 | | 3 | MJ/Kg benzene | 0.07 | |
| Fission | MJ/Kg benzene | 0.2 | | 3 | MJ/Kg benzene | 0.2 | |

Probably different mix in US

Material input

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| Oil | MJ/Kg benzene | 27.84 | | 3 | Kg/Kg benzene | 0.624041192 | |
| Natural Gas | MJ/Kg benzene | 36.18 | | 3 | Kg/Kg benzene | 0.786521739 | |
| Coal | MJ/Kg benzene | 0.01 | | 3 | Kg/Kg benzene | 0.000358269 | |
| Iron ore | Kg/Kg benzene | 0.00015 | | 3 | Kg/Kg benzene | 0.00015 | |
| limestone | Kg/Kg benzene | 0.00011 | | 3 | Kg/Kg benzene | 0.00011 | |
| Bauxite | Kg/Kg benzene | 0.00022 | | 3 | Kg/Kg benzene | 0.00022 | |
| Rock salt | Kg/Kg benzene | 0.0058 | | 3 | Kg/Kg benzene | 0.0058 | |
| Clay | Kg/Kg benzene | 0.00002 | | 3 | Kg/Kg benzene | 0.00002 | |
| Water | Kg/Kg benzene | 2.209 | | 3 | Kg/Kg benzene | 2.209 | |

Output
Air

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| TSP | Kg/Kg benzene | 0.0009 | | | Kg/Kg benzene | 0.0009 | |
| SOx | Kg/Kg benzene | 0.003 | | | Kg/Kg benzene | 0.003 | |
| NOx | Kg/Kg benzene | 0.0068 | | | Kg/Kg benzene | 0.0068 | |
| CO | Kg/Kg benzene | 0.0006 | | | Kg/Kg benzene | 0.0006 | |
| CO2 | Kg/Kg benzene | 0.54 | | | Kg/Kg benzene | 0.54 | |
| H2S | Kg/Kg benzene | 0.000005 | | | Kg/Kg benzene | 0.000005 | |
| HCl | Kg/Kg benzene | 0.00015 | | | Kg/Kg benzene | 0.00015 | |
| total HC's | Kg/Kg benzene | 0.0083 | | | Kg/Kg benzene | 0.0083 | |
| Heavy metals | Kg/Kg benzene | 0.000001 | | | Kg/Kg benzene | 0.000001 | |

Water

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| COD | Kg/Kg benzene | 0.0002 | | | Kg/Kg benzene | 0.0002 | |
| BOD | Kg/Kg benzene | 0.00002 | | | Kg/Kg benzene | 0.00002 | |
| Acid as H+ | Kg/Kg benzene | 0.00004 | | | Kg/Kg benzene | 0.00004 | |
| Nitrate | Kg/Kg benzene | 0.000001 | | | Kg/Kg benzene | 0.000001 | |
| Metal ions | Kg/Kg benzene | 0.00036 | | | Kg/Kg benzene | 0.00036 | |
| Cl2 | Kg/Kg benzene | 0.00009 | | | Kg/Kg benzene | 0.00009 | |
| ammonia | Kg/Kg benzene | 0.00009 | | | Kg/Kg benzene | 0.00009 | |
| dissolved organics | Kg/Kg benzene | 0.000015 | | | Kg/Kg benzene | 0.000015 | |
| suspended particles | Kg/Kg benzene | 0.00012 | | | Kg/Kg benzene | 0.00012 | |
| Crude | Kg/Kg benzene | 0.0001 | | | Kg/Kg benzene | 0.0001 | |
| dissolved substances | Kg/Kg benzene | 0.00054 | | | Kg/Kg benzene | 0.00054 | |
| HC's | Kg/Kg benzene | 0.00008 | | | Kg/Kg benzene | 0.00008 | |
| unknown (N) | Kg/Kg benzene | 0.000001 | | | Kg/Kg benzene | 0.000001 | |
| **Solid waste** | | | | | | | |
| Production waste (not innert) | Kg/Kg benzene | 0.00966 | | | Kg/Kg benzene | 0.00966 | |
| Toxic chemicals | Kg/Kg ethylene | 0.000001 | | | Kg/Kg ethylene | 0.000001 | |

Sheet End ========= ============ ============ ============ ============ ============ =============== ============ ============ ========= ========= =========

| Coal type | Moisture | Sulfur | | Heat value | | | | |
|---|---|---|---|---|---|---|---|---|
| | % | % | %dry | Btu/lb | Btu/lbdry | | | |
| Sub bit C | 26 | 0.3 | 0.41 | 8230 | 11122 | | | |
| HV bit A | 2.9 | 0.6 | 0.62 | 14170 | 14593 | low sulfur coal heating value | | |
| Sub bit B | 22.2 | 0.5 | 0.64 | 9610 | 12352 | | | |
| Brown CGerman | 55 | 0.3 | 0.67 | 4830 | 10733 | | | |
| Sub bit A | 13.9 | 0.6 | 0.70 | 10330 | 11998 | SD= | 1296 | 0.108 |
| Meta Anthracite | 9 | 0.7 | 0.77 | 10080 | 11077 | Avg= | 11979 | |
| LV bit | 2.9 | 0.8 | 0.82 | 14400 | 14830 | median | | |
| Anthracite | 4.3 | 0.8 | 0.84 | 12880 | 13459 | | | |
| Lignite | 36.8 | 0.9 | 1.42 | 7000 | 11076 | | | |
| MV bit | 2.4 | 1.5 | 1.54 | 14490 | 14846 | | | |
| Semi anthracite | 2.1 | 1.7 | 1.74 | 13700 | 13994 | | | |
| HV bit B | 6.7 | 2.6 | 2.79 | 12390 | 13280 | | | |
| HV bit C | 15.4 | 2.9 | 3.43 | 10740 | 12695 | | | |

bit=Bituminous
V=Volatility
L=low
M=Medium
H=high

Source: Kirk Othmer vol 4 1949

Natural gas

| mol% | Mwt | heat valu MJ/M^3 | Rio Arrib | Terrell, T | Stanton, | San Jua | Olds Fie | Cliffside, Texas | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Methane | 16.04 | 37.57 | 96.91 | 45.64 | 67.56 | 77.28 | 52.34 | 65.8 | | |
| ethane | 30.07 | 65.83 | 1.33 | 0.21 | 6.23 | 11.18 | 0.41 | 3.8 | | |
| propane | 44.1 | 93.6 | 0.19 | | 3.18 | 5.83 | 0.14 | 1.7 | | |
| butane | 58.12 | 121 | 0.05 | | 1.42 | 2.34 | 0.16 | 0.8 | | |
| pentane | 72.15 | 148.8 | 0.02 | | 0.04 | 1.18 | 0.41 | 0.5 | | |
| CO2 | 44.01 | 0 | 0.82 | 53.93 | 0.07 | 0.8 | 8.22 | | | |
| H2S | 34.08 | 23.7 | | 0.01 | | | 35.79 | | | |
| N2 | 28.01 | 0 | 0.68 | 0.21 | 21.14 | 1.39 | 2.53 | 25.6 | avg | SD (rel) |
| Mol wt: | | | 16.63 | 31.18 | 20.92 | 21.28 | 25.49 | 20.45 | 19.61 | 10.79% |
| heating | MJ/M^3 | | 37.6 | 17.3 | 34.9 | 46.8 | 30 | 30.7 | 39.77 | 12.81% |
| | MJ/KG | | 50.66 | 12.43 | 37.37 | 49.25 | 26.36 | 33.63 | 45.76 | 13.03% |
| | 0.0224M^3/mol | | | too high CO2 content for use | | | too high Sulfur content | too low heating value(?) | | |

Source: Kirk Othmer Ed 4 vol 12 1993

MJ/m^3

Heating values for processed city natural gas:
source Perry 6 (1964)
averaged from table 9-14

Btu/scf 1050

Synopsis of table 9-14

| mol% | Mwt | heat valu MJ/M^3 | Baltimor Md | Columbu Ohio | Houston Tx | Burming Al | Washing DC | Phoenix Az | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Methane | 16.04 | 37.57 | 94.4 | 93.14 | 92.5 | 93.14 | 95.15 | 87.37 | | |
| ethane | 30.07 | 65.83 | 3.4 | 3.58 | 4.8 | 2.5 | 2.84 | 8.11 | | |
| propane | 44.1 | 93.6 | 0.6 | 0.66 | 2 | 0.67 | 0.63 | 2.26 | | |
| butane | 58.12 | 121 | 0.5 | 0.22 | 0.3 | 0.32 | 0.24 | 0.13 | | |
| pentane | 72.15 | 148.8 | 0 | 0.09 | 0 | 0.12 | 0.05 | 0 | | |
| CO2 | 44.01 | 0 | 0.6 | 0.85 | 0.27 | 1.06 | 0.62 | 0.61 | | |
| H2S | 34.08 | 23.7 | | 0.01 | | | | | | |
| N2 | 28.01 | 0 | 0.5 | 0.21 | 21.14 | 2.14 | 0.42 | 1.37 | avg | SD (rel) |
| Mol wt: | | | 17.13 | 16.94 | 23.38 | 17.33 | 16.96 | 18.18 | 18.32 | 15.84% |
| heating | MJ/M^3 | | 39.2 | 38.34 | 38.46 | 38.2 | 38.87 | 39.95 | 38.84 | 1.10% |
| | MJ/KG | | 51.27 | 50.71 | 36.84 | 49.37 | 51.32 | 49.22 | 48.12 | 13.30% |

0.0224M^3/mol

Sheet Title: Chlorine

Sheet Description: This page calculates the vendor-independent emissions from european manufacture of chlorine gas.

References/Citations: SimaPro3 (entry of Nov 18 94)
Average european data for NaOH/Cl2 producers.
taken from:
PWMI/APME, Ecoprofiles of the European plastics industry, 1992-1994
report 6, tbl 15 pg 13 and report 5 (allocation)

Summary Output

Co-product Allocation Calculations

| Co-product | Quantity | Units | |
|---|---|---|---|
| chlorine | 1.00E+00 | Kg | |
| NaOH | | | data after allocation |
| Total | 1 | Kg | |

| | LCI components | Unallocated Units | Quantity | Std. Dev. | Allocated Units | Quantity | Std. Dev. | DQI |
|---|---|---|---|---|---|---|---|---|
| | Air | | | | | | | |
| | Water | | | | | | | |
| | COD | Kg/Kg chlorine | 0.00001 | | | | | 3 |
| | BOD | Kg/Kg chlorine | 0.000003 | | | | | 3 |
| | Acid as H+ | Kg/Kg chlorine | 0.00034 | | | | | 3 |
| | Metal ions | Kg/Kg chlorine | 0.00009 | | | | | 3 |
| | Cl2 | Kg/Kg chlorine | 0.042 | | | | | 3 |
| | suspended solid | Kg/Kg chlorine | 0.002 | | | | | 3 |
| | miscelanious dis | Kg/Kg chlorine | 0.00005 | | | | | 3 |
| | sodium | Kg/Kg chlorine | 0.0028 | | | | | 3 |
| | Solid Wastes | | | | | | | |
| | Production waste | Kg/Kg chlorine | 0.099 | | | | | 3 |
| | Resource Consumption | | | | | | | |
| fuel | Natural Gas | Kg/Kg chlorine | 0.088043478 | | | 3375000 | | 3 |
| fuel | Crude Oil | Kg/Kg chlorine | 0.079350065 | | | 14.11883921 | | 3 |

| | | | | | |
|---|---|---|---|---|---|
| fuel | Coal | Kg/Kg chlorine | 0.242547977 | 43.15681238 | 3 |
| | Hydropower | MJ/Kg chlorine | 0.72 | | |
| | Fission | MJ/Kg chlorine | 6.14 | | |
| | Iron ore | Kg/Kg chlorine | 0.00065 | | |
| | limestone | Kg/Kg chlorine | 0.0186 | | |
| | Rock salt | Kg/Kg chlorine | 1.21 | | |
| | Water | Kg/Kg chlorine | 0.9 | | |
| | sand | Kg/Kg chlorine | 0.00002 | | |

Notes: This section is where the project specfic calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors

| Unit from | Unit to | Multiplier | Reference | |
|---|---|---|---|---|
| BTU | J | 1055.056 | CRC, 66th Edition | |
| Wh | J | 3600 | CRC, 66th Edition | |
| bbl CrO | BTU CrO | 5800000 | Chemical Engineers' Handbook, 6th ed. | |
| bbl | gal | 42 | Chemical Engineers' Handbook, 6th ed. | |
| gal diesel | BTU diesel | 118500 | Chemical Engineers' Handbook, 6th ed., Figure 9-4 @ S.G. = .76 and sulfur = 0.5% | |
| gal | L | 3.785412 | CRC, 66th Edition | |
| kg | lb | 2.2046226 | CRC, 66th Edition | |
| yr | day | 365 | | |
| m^3 | bbl (petroleum) | 6.289811 | CRC, 66th Edition | |
| gal CrO | lb CrO | 7.2 | | |
| ton | lb | 2000 | | |
| gal fuel oil | BTU fuel oil | 138000 | | |
| cu. ft NG | BTU NG | 1032 | Chemical Engineers' Handbook, 6th ed. | |
| lb Coal (dry) | BTU Coal | 12000 | calculation page B | SD=11% |
| kg NG | MJ NG | 46 | Calculated page C | SD=13% |

Calculations

Ethylene Production

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| chlorine (polymer) | 1 Kg | | | 3 | | | |
| chlorine (other) | | | | | | | |
| | | | | | | 0 | |

SimaPro3
Average data for 19 european cracking fascilities producing monomer quality chlorine.
taken from:

PWMI/APME, Ecoprofiles of the European plastics industry, 1992-1994
report 2, tbl 36 pg 21

Energy input

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| Coal | MJ/Kg chlorine | 6.77 | | 3 | Kg/Kg chlorine | 0.242547977 | |
| Oil | MJ/Kg chlorine | 3.54 | | 3 | Kg/Kg chlorine | 0.079350065 | |
| Natural Gas | MJ/Kg chlorine | 4.05 | | 3 | Kg/Kg chlorine | 0.088043478 | |
| Hydropower | MJ/Kg chlorine | 0.72 | | 3 | MJ/Kg chlorine | 0.72 | |
| Fission | MJ/Kg chlorine | 6.14 | | 3 | MJ/Kg chlorine | 6.14 | |

Probably different mix in US

Material input

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| Oil | MJ/Kg chlorine | 0 | | 3 | Kg/Kg chlorine | 0 | |
| Natural Gas | MJ/Kg chlorine | 0 | | 3 | Kg/Kg chlorine | 0 | |
| Coal | MJ/Kg chlorine | 0 | | 3 | Kg/Kg chlorine | 0 | |
| Iron ore | Kg/Kg chlorine | 0.00065 | | 3 | Kg/Kg chlorine | 0.00065 | |
| limestone | Kg/Kg chlorine | 0.0186 | | 3 | Kg/Kg chlorine | 0.0186 | |
| Bauxite | Kg/Kg chlorine | 0 | | 3 | Kg/Kg chlorine | 0 | |
| Rock salt | Kg/Kg chlorine | 1.21 | | 3 | Kg/Kg chlorine | 1.21 | |
| Clay | Kg/Kg chlorine | 0 | | 3 | Kg/Kg chlorine | 0 | |
| Water | Kg/Kg chlorine | 0.9 | | 3 | Kg/Kg chlorine | 0.9 | |
| sand | Kg/Kg chlorine | 0.00002 | | 3 | Kg/Kg chlorine | 0.00002 | |

Output
Air

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| TSP | Kg/Kg chlorine | 0.0035 | | | Kg/Kg chlorine | 0.0035 | |
| SOx | Kg/Kg chlorine | 0.012 | | | Kg/Kg chlorine | 0.012 | |
| NOx | Kg/Kg chlorine | 0.007 | | | Kg/Kg chlorine | 0.007 | |
| CO | Kg/Kg chlorine | 0.0008 | | | Kg/Kg chlorine | 0.0008 | |
| CO2 | Kg/Kg chlorine | 1.21 | | | Kg/Kg chlorine | 1.21 | |
| H2S | Kg/Kg chlorine | 0 | | | Kg/Kg chlorine | 0 | |
| HCl | Kg/Kg chlorine | 0.00018 | | | Kg/Kg chlorine | 0.00018 | |
| total HC's | Kg/Kg chlorine | 0.006 | | | Kg/Kg chlorine | 0.006 | |
| Heavy metals | Kg/Kg chlorine | 0.000002 | | | Kg/Kg chlorine | 0.000002 | |

Water

| | Raw/ | Raw/ | Raw/ | | Transformed | Transformed | Transformed |
|---|---|---|---|---|---|---|---|

| LCI component | Input Units | Input Quan. | Input Std. Dev. | DQI | Units | Quan. | Std. Dev. |
|---|---|---|---|---|---|---|---|
| COD | Kg/Kg chlorine | 0.00001 | | | Kg/Kg chlorine | 0.00001 | |
| BOD | Kg/Kg chlorine | 0.000003 | | | Kg/Kg chlorine | 0.000003 | |
| Acid as H+ | Kg/Kg chlorine | 0.00034 | | | Kg/Kg chlorine | 0.00034 | |
| Nitrate | Kg/Kg chlorine | 0 | | | Kg/Kg chlorine | 0 | |
| Metal ions | Kg/Kg chlorine | 0.00009 | | | Kg/Kg chlorine | 0.00009 | |
| Cl2 | Kg/Kg chlorine | 0.042 | | | Kg/Kg chlorine | 0.042 | |
| ammonia | Kg/Kg chlorine | 0 | | | Kg/Kg chlorine | 0 | |
| dissolved organics | Kg/Kg chlorine | 0 | | | Kg/Kg chlorine | 0 | |
| suspended particles | Kg/Kg chlorine | 0.002 | | | Kg/Kg chlorine | 0.002 | |
| Crude | Kg/Kg chlorine | 0 | | | Kg/Kg chlorine | 0 | |
| dissolved substances | Kg/Kg chlorine | 0.00005 | | | Kg/Kg chlorine | 0.00005 | |
| HC's | Kg/Kg chlorine | 0 | | | Kg/Kg chlorine | 0 | |
| sodium | Kg/Kg chlorine | 0.0028 | | | Kg/Kg chlorine | 0.0028 | |
| Solid waste | | | | | | | |
| Production waste (not innert) | Kg/Kg chlorine | 0.099 | | | Kg/Kg chlorine | 0.099 | |
| Toxic chemicals | Kg/Kg chlorine | 0.00002 | | | Kg/Kg chlorine | 0.000001 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| CrO from Alaska | 1000 bbl/day | 1798 | | | ton/yr | 99228024 | |
| Total | | | | | ton/yr | 99228024 | |
| Water Shipping - Lower 48 | mi | 0 | | | ton-mi/yr | 0 | |
| Water Shipping - Alaska | mi | 2439.6 | | | ton-mi/yr | 2.42077E+11 | |

Crude Oil Transport

Association of Oil Pipe Lines Data for 1990

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| Pipelines | mi | 0 | | | | | |
| Water | mi | 2439.6 | | | | | |
| Highway/Motor Carrier | mi | 1000 | | | | | |
| Rail | mi | 697 | | | | | |

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| Pipelines | BTU/ton-mi | 0 | | | | | |
| Water | BTU/ton-mi | 361 | | | gal fuel/bbl CrO | 0.964936049 | |
| Highway/Motor Carrier | BTU/ton-mi | 434 | | | gal fuel/bbl CrO | 0.553762025 | |
| Rail | BTU/ton-mi | 434 | | | gal fuel/bbl CrO | 0.385972132 | |

Water Transport Emissions

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| SOx | lb/1000 gal fuel | 27 | | | kg/bbl CrO | 0.011817566 | |
| CO | lb/1000 gal fuel | 100 | | | kg/bbl CrO | 0.043768763 | |
| HC | lb/1000 gal fuel | 50 | | | kg/bbl CrO | 0.021884382 | |
| NOx | lb/1000 gal fuel | 280 | | | kg/bbl CrO | 0.122552537 | |
| HC - transfer | lb/1000 gal hauled | 0.97 | | | kg/bbl CrO | 0.018479353 | |

Highway Transport Emissions

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| HC | lb/1000 gal fuel | 5.4572 | | | kg/bbl CrO | 0.001370752 | |
| CO | lb/1000 gal fuel | 15.3321 | | | kg/bbl CrO | 0.003851151 | |
| NOx | lb/1000 gal fuel | 18.6622 | | | kg/bbl CrO | 0.004687613 | |
| HC - transfer | lb/1000 gal hauled | 3.25 | | | kg/bbl CrO | 0.061915359 | |

Railroad Transport Emissions

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| TSP | lb/1000 gal fuel | 25 | | | kg/bbl CrO | 0.00437685 | |
| SOx | lb/1000 gal fuel | 57 | | | kg/bbl CrO | 0.009979219 | |
| CO | lb/1000 gal fuel | 130 | | | kg/bbl CrO | 0.022759622 | |
| HC | lb/1000 gal fuel | 94 | | | kg/bbl CrO | 0.016456957 | |
| NOx | lb/1000 gal fuel | 370 | | | kg/bbl CrO | 0.064777386 | |
| Aldehydes | lb/1000 gal fuel | 5.5 | | | kg/bbl CrO | 0.000962907 | |
| Organic Acids | lb/1000 gal fuel | 7 | | | kg/bbl CrO | 0.001225518 | |
| HC - transfer | lb/1000 gal hauled | 3.25 | | | kg/bbl CrO | 0.061915359 | |

Sheet End

| | |
|---|---|
| Sheet Title: | Isopropanol (from Propene and Isobutelene. Isopropanol is used in production of TNAZ) |
| Sheet Description: | Emissions are from TRI database.<br>Engineering calculation of the Energy requirements and precursor requirements .<br>This page calculates the vendor emissions from a plant producing Isopropanol.<br>Not included are raw material production or extraction or water use. |

References/Citations:


Faith Keyes and Clarke's Industrial Chemicals
By F. A. Lowenheim, M. K. Moran
Wiley Interscience, 1975

Perry's Chemical Engineers' Handbook, 6th ed.
McGraw Hill, 1984

AP 42 Ed 4 (1985)
US EPA

SRI Directory of Chemical Producers, US
1993, 1991 editions
SRI International, Menlo Park, CA

US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993
US International Trade Commission, 11.1994

CRC Handbook of Chemistry and Physics, 66th Edition


Summary Output

Co-product Allocation Calculations

Source: US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993
US International Trade Commission, 11.1994

| Mwt | Co-product | Quantity | Units | Quantity | Units | BP deg C | Sp G | Vapor density relative to air |
|---|---|---|---|---|---|---|---|---|
| 60.0956 | Isopropanol | 1.00E+00 | kg | 1.00E+00 | kg | 8.2 | 1.392 | 3.4 |
| | Total | 1.00E+00 | Kg | 1.00E+00 | Kg | | | |

Notes:

| LCI components | Unallocated Units | Quantity | Std. Dev. | Allocated Units | Quantity | Std. Dev. | DQI |
|---|---|---|---|---|---|---|---|
| **Air** | | | | | | | |
| Isopropanol | Kg/kg Isopropa | 0.000651899 | | Kg/kg Isopropa | 0.000651899 | | 5 |
| Propene | Kg/kg Isopropa | 2.56305E-05 | | Kg/kg Isopropa | 2.56305E-05 | | 5 |
| **Water** | | | | | | | |
| Na2SO4 | Kg/kg Isopropa | 0.016909798 | | Kg/kg Isopropa | 0.016909798 | | 5 |
| Solid Wastes | | | | | | | |
| Resource Consumption | | | | | | | |
| Heat Energy (fos | MJ/Kg Isopropa | 5.205045039 | | MJ/Kg Isopropa | 5.205045039 | | 3 |

| | | | | | |
|---|---|---|---|---|---|
| Electric Power | MJ/Kg Isopropa | 3.71126E-05 | MJ/Kg Isopropa | 3.71126E-05 | 3 |
| Propene | Kg/kg Isopropa | 0.989010989 | Kg/kg Isopropa | 0.989010989 | 5 |
| sulfuric acid | Kg/kg Isopropa | 0.011675824 | Kg/kg Isopropa | 0.011675824 | 4 |
| NaOH | Kg/kg Isopropa | 0.009523461 | Kg/kg Isopropa | 0.009523461 | 3 |

Notes: This section is where the project specfic calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors

| Unit from | Unit to | Multiplier | Reference | |
|---|---|---|---|---|
| BTU | J | 1055.056 | CRC, 66th Edition | |
| Wh | J | 3600 | CRC, 66th Edition | |
| bbl CrO | BTU CrO | 5800000 | Chemical Engineers' Handbook, 6th ed. | |
| bbl | gal | 42 | Chemical Engineers' Handbook, 6th ed. | |
| gal diesel | BTU diesel | 118500 | Chemical Engineers' Handbook, 6th ed., Figure 9-4 @ S.G. = .76 and sulfur = 0.5% | |
| gal | L | 3.785412 | CRC, 66th Edition | |
| kg | lb | 2.2046226 | CRC, 66th Edition | |
| yr | day | 365 | | |
| p.s.i. | feet water | 2.03666 | CRC, 66th Edition | |
| m^3 | bbl (petroleum) | 6.289811 | CRC, 66th Edition | |
| gal CrO | lb CrO | 7.2 | | |
| ton | lb | 2000 | | |
| gal fuel oil | BTU fuel oil | 138000 | | |
| cu. ft NG | BTU NG | 1032 | Chemical Engineers' Handbook, 6th ed. | |
| lb Coal (dry | BTU Coal | 12000 | calculation page B | SD=11% |
| kg NG. | MJ NG | 46 | Calculated page C | SD=13% |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| d Isopropan | 0.74 | rel to Water | molar | | | | kg air per kg |
| Mw Chlorin | 70.9 | | dry air composition | | Mwt | mass composition | component |
| Mw ClBz | 112.56 | | N2 | 0.78084 | 28.0134 | 0.75521 | 1.324134 |
| Mw Cl2Bz | 147.01 | | O2 | 0.20946 | 31.9988 | 0.231406 | 4.321406 |
| Mw HCl | 36.4609 | | CO2 | 0.00033 | 44.01 | 0.000501 | 1994.319 |
| Mw NaOH | 39.9971 | | Ar | 0.00934 | 39.948 | 0.012882 | 77.62792 |
| | | | total | 0.99997 | 28.96409 | 1 | |

| | | | | | |
|---|---|---|---|---|---|
| Ideal gas density at 15 C (60 F) | | | | air (dry) | |
| 0.042296 | mol/liter | 42.29634021 | mol/m^3 | 1.225075005 | kg/m^3 |

**Calculations**

**Isopropanol Production** 1993

Source: US ITC 2810 11.94 Synthetic Organic Che Kg 576845000

US Production and Sales, 1993

**Isopropanol production capacity**

Source: Chem & Eng. News

| | | | |
|---|---|---|---|
| Chemical Profile | Mlb | 1800 | |
| Aug 9 '93 | Utilization ratio: | 0.70651418 | |
| | | Capacity Mlb | Calculated production: Mlb |
| Exxon | Baton Rouge, LA 70821 | 650 | 459.2342169 |

| | | | |
|---|---|---|---|
| Shell Oil Co. | Deer Park, TX 77536 | 600 | 423.9085079 |
| Union Carbide | Texas City, TX 77590 | 550 | 388.5827989 |

Source: Emissions:
TRI database, 1993 data

| The following reported emissions were ascribed to Isopropanol production | | Isopropanol | Propene | sulfuric acid | Isopropyl ether |
|---|---|---|---|---|---|
| Exxon | Air | | 3.40E+05 | 2.00E+00 | |
| | Water | | 0.00E+00 | | |
| Shell Oil Co. | Air | | 3.34E+05 | 0.00E+00 | |
| | Water | | 0.00E+00 | | |
| Union Carbide | Air | | 1.55E+05 | 3.26E+04 | |
| | Water | | 0.00E+00 | | |

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| Fossil fuel (general) | MJ/kg Isopropa | 5.20504504 | | | MJ/kg Isopropanol | 5.205045039 | |
| Coal | MJ/kg Isopropa | 0 | | | Kg/kg Isopropanol | 0 | |
| Oil | MJ/kg Isopropa | 0 | | | Kg/kg Isopropanol | 0 | |
| Natural Gas | MJ/kg Isopropa | 0 | | | Kg/kg Isopropanol | 0 | |
| Hydropower | MJ/kg Isopropa | 0 | | | | | |
| Fission | MJ/kg Isopropa | 0 | | | | | |
| Electricity (generic) | MJ/kg Isopropa | 3.71126E-05 | | | MJ/kg Isopropanol | 3.71126E-05 | |

| | | D H evap cal/m | Mwt | D H v MJ/Kg | Kg/kg Isopropanol | MJ/Kg Propanol | |
|---|---|---|---|---|---|---|---|
| Isopropanol evaporation | from acid | 10063.5 | 60.0956 | 0.700645039 | 1 | 0.700645039 | |
| water evaporation | Acid reconstitution | | | 2.2522 | 2 | 4.5044 | |
| | | CRC 66 | | Perry's 6 | | 5.205045039 | heat load |

Heating load is disregarded because of the overwhelming energy requirements of evaporation and the probable recovery of that energy for other heating purposes.

Cooling
water

| | | | |
|---|---|---|---|
| | 25 | deg C temp rise | Condensation |
| | 0.1046 | heat removal MJ/kg water | |
| | 5.205045 | MJ/kg product | heat load |
| c water | 49.76142 | Kg/Kg product | 0.7 efficiency |

7.87E-05 kJ Elec/Kg  Based on viscosity and density of water for a 250 ft static head per pumping stage
in 40hr week & 52 week year daytime operation. multiply by specific gravity of material
and relative viscosity to that of water.

| | | kg flow/kg propar | representative | Sp grav | Sp visc | | | | |
|---|---|---|---|---|---|---|---|---|---|
| distillation botto | to storage | 1 | Isopropanol | 0.7855 | 2.496666667 | MJ/kg Isopropa | 1.54392E-07 | | |
| storage | to reactor | 0.25 | mineral oil/whit | 0.7628 | 2.18 | MJ/kg Isopropa | 3.27284E-08 | | 25C |
| water dilution 2 | to acid boile | 12 | sulfuric acid +w | 2.02196 | 1.966466667 | MJ/kg Isopropa | 3.75628E-06 | | 83 C |
| acid+propene a | to dilution | 5 | sulfuric acid +w | 1.899 | 21.7403 | MJ/kg Isopropa | 1.62509E-05 | | 25 C |
| clean aacid | to absorber | 4 | sulfuric acid +w | 1.899 | 21.7403 | MJ/kg Isopropa | 1.30008E-05 | | 25 C |
| water | | 49.76142485 | | 1 | 1 | | 3.91752E-06 | | |
| | | | | CRC 66 | CRC 66 | | 3.71126E-05 | total pumping energy per kg prod | |

| Absorber materials at 4*weight of product stream | | | | | |
|---|---|---|---|---|---|
| 2 | 5.5 | 8 | 8 | 1 | 24.5 |
| 6 | 2.5 | | | 7 | 15.5 |

Co-Products:
source: See from above

40

Resources: Faith, Keyes and Clark'e Industrial chemicals

| | LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. | |
|---|---|---|---|---|---|---|---|---|---|
| | Oil | Kg/kg Isopropa | 0 | | | Kg/kg Isopropanol | 0 | | |
| | Natural Gas | Kg/kg Isopropa | 0 | | | Kg/kg Isopropanol | 0 | | |
| | Coal | Kg/kg Isopropa | 0 | | | Kg/kg Isopropanol | 0 | | |
| 42.0804 | Propene | Kg/.91kg Isopro | 0.9 | | 5 | Kg/kg Isopropanol | 0.989010989 | | |
| 98.0734 | sulfuric acid | Kg/.91kg Isopro | 0.010625 | | 4 | Kg/kg Isopropanol | 0.011675824 | | |
| | "Mineral oil" | Kg/kg Isopropa | 0 | | | Kg/kg Isopropanol | 0 | | |
| 39.9971 | NaOH | Kg/.91kg Isopro | 0.00866635 | | 3 | Kg/kg Isopropanol | 0.009523461 | | Eng Estimate based on H2SO4 make up for treatment |
| | Water | Kg/kg Isopropa | 0 | | | Kg/kg Isopropanol | 0 | | |

**Air**

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| TSP | lb/Exxon +Shel | 0 | | | Kg/kg Isopropanol | 0 | |
| SOx | lb/Exxon +Shel | 0 | | | Kg/kg Isopropanol | 0 | |
| NOx | lb/Exxon +Shel | 0 | | | Kg/kg Isopropanol | 0 | |
| Cl2 | lb/Exxon +Shel | 0 | | | Kg/kg Isopropanol | 0 | |
| Isopropanol | lb/Exxon +Shel | 0.00E+00 | | 5 | Kg/kg Isopropanol | 0 | |
| Propene | lb/Exxon +Shel | 8.29E+05 | | 5 | Kg/kg Isopropanol | 0.000651899 | |
| sulfuric acid | lb/Exxon +Shel | 3.26E+04 | | 5 | Kg/kg Isopropanol | 2.56305E-05 | |
| Isopropyl ether | lb/Exxon +Shel | 0.00E+00 | | 5 | Kg/kg Isopropanol | 0 | |
| HC total | lb/Exxon +Shel | 0.00E+00 | | | Kg/kg Isopropanol | 0 | |
| Heavy meta(Cd+Ni+Cr) | lb/Exxon +Shel | 0 | | | Kg/kg Isopropanol | 0 | |

**Water**

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| COD | lb/Exxon +Shel | 0 | | | Kg/kg Isopropanol | 0 | |
| BOD | lb/Exxon +Shel | 0 | | | Kg/kg Isopropanol | 0 | |
| Acid, H+ (Phosphoric) | lb/Exxon +Shel | 0 | | | Kg/kg Isopropanol | 0 | |
| Metal ions | lb/Exxon +Shel | 0 | | | Kg/kg Isopropanol | 0 | |
| Na2SO4 in water | lb/Exxon +Shel | 0 | | 3 | Kg/kg Isopropanol | 0.016909798 | |
| Isopropanol | lb/Exxon +Shel | 0.00E+00 | | | Kg/kg Isopropanol | 0 | |
| Propene | lb/Exxon +Shel | 0.00E+00 | | | Kg/kg Isopropanol | 0 | |
| sulfuric acid | lb/Exxon +Shel | 0.00E+00 | | | Kg/kg Isopropanol | 0 | |
| Isopropyl ether | lb/Exxon +Shel | 0.00E+00 | | | Kg/kg Isopropanol | 0 | |
| Heavy metals (Cadmium, Nic | lb/Exxon +Shel | 0 | | | Kg/kg Isopropanol | 0 | |

**Solid waste**

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| Production waste (not innert) | lb/Exxon +Glob | 0 | | | Kg/kg Isopropanol | 0 | |
| Heavy metals (Cadmium, Nic | lb/Exxon +Glob | 0 | | | Kg/kg Isopropanol | 0 | |

**Offsite Transfer**

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|

Sheet Title: Propylene (for polypropylene production)

Sheet Description: This page calculates the vendor-independent emissions from european refineries producing monomer quality propylene
Included are oil extraction and transportation from the well head to the refinery.

References/Citations: SimaPro3 (entry of Nov 18 94)
Average data for 19 european cracking fascilities producing monomer quality ethylene.
taken from:
PWMI/APME, Ecoprofiles of the European plastics industry, 1992-1994
report 2, tbl 36 pg 21

Summary Output
Co-product Allocation Calculations

| Co-product | Quantity | Units |
|---|---|---|
| Propylene | 1.00E+00 | Kg |
| Total | 1 | Kg |

| LCI components | Unallocated Units | Quantity | Std. Dev. | Allocated Units | Quantity | Std. Dev. | DQI |
|---|---|---|---|---|---|---|---|
| Air | | | | | | | |
| TSP | Kg/Kg propylene | 0.0008 | | | | | 3 |
| SOx | Kg/Kg propylene | 0.004 | | | | | 3 |
| NOx | Kg/Kg propylene | 0.006 | | | | | 3 |
| CO | Kg/Kg propylene | 0.0004 | | | | | 3 |
| CO2 | Kg/Kg propylene | 0.528 | | | | | 3 |
| H2S | Kg/Kg propylene | 0.00001 | | | | | 3 |
| HCl | Kg/Kg propylene | 0.00001 | | | | | 3 |
| total HC's | Kg/Kg propylene | 0.008 | | | | | 3 |
| other organic | Kg/Kg propylene | 0.000001 | | | | | 3 |
| Heavy metals | Kg/Kg propylene | 0.000001 | | | | | 3 |
| Water | | | | | | | |
| COD | Kg/Kg propylene | 0.0002 | | | | | 3 |
| BOD | Kg/Kg propylene | 0.00003 | | | | | 3 |
| Acid as H+ | Kg/Kg propylene | 0.00004 | | | | | 3 |
| Metal ions | Kg/Kg propylene | 0.0002 | | | | | 3 |
| Cl2 | Kg/Kg propylene | 0.00005 | | | | | 3 |

| | | | | | |
|---|---|---|---|---|---|
| | Dissolved Organ | Kg/Kg propylene | 0.00002 | | 3 |
| | suspended solid | Kg/Kg propylene | 0.0002 | | 3 |
| | crude oil | Kg/Kg propylene | 0.0001 | | 3 |
| | miscelanious dis | Kg/Kg propylene | 0.0004 | | 3 |
| | Phenol | Kg/Kg propylene | 0.00007 | | 3 |
| | Solid Wastes | | | | |
| | Production waste | Kg/Kg propylene | 0.009 | | 3 |
| Resource Consumption | | | | | |
| | Natural Gas | Kg/Kg propylene | 0.514130435 | 19708333.33 | 3 |
| | Coal | Kg/Kg propylene | 0.000358269 | | |
| fuel | Coal | Kg/Kg propylene | 0.020063053 | 3.569839724 | 3 |
| | Hydropower | MJ/Kg propylene | 0.12 | | |
| | Fission | MJ/Kg propylene | 0.23 | | |
| | Iron ore | Kg/Kg propylene | 0.0002 | | |
| | limestone | Kg/Kg propylene | 0.0001 | | |
| | Bauxite | Kg/Kg propylene | 0.0003 | | |
| | Rock salt | Kg/Kg propylene | 0.006 | | |
| | Clay | Kg/Kg propylene | 0.00002 | | |
| | Water | Kg/Kg propylene | 1.6 | | |

Notes: This section is where the project specfic calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors

| Unit from | Unit to | Multiplier | Reference |
|---|---|---|---|
| BTU | J | 1055.056 | CRC, 66th Edition |
| Wh | J | 3600 | CRC, 66th Edition |
| bbl CrO | BTU CrO | 5800000 | Chemical Engineers' Handbook, 6th ed. |
| bbl | gal | 42 | Chemical Engineers' Handbook, 6th ed. |
| gal diesel | BTU diesel | 118500 | Chemical Engineers' Handbook, 6th ed., Figure 9-4 @ S.G. = .76 and sulfur = 0.5% |
| gal | L | 3.785412 | CRC, 66th Edition |
| kg | lb | 2.2046226 | CRC, 66th Edition |
| yr | day | 365 | |
| m^3 | bbl (petroleum) | 6.289811 | CRC, 66th Edition |
| gal CrO | lb CrO | 7.2 | |
| ton | lb | 2000 | |
| gal fuel oil | BTU fuel oil | 138000 | |
| cu. ft NG | BTU NG | 1032 | Chemical Engineers' Handbook, 6th ed. |
| lb Coal (dry) | BTU Coal | 12000 | calculation page B SD=11% |

Calculations

| kg NG | MJ NG | 46 | Calculated page C | SD=13% |
|---|---|---|---|---|

Ethylene Production

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| Propylene (polymer) | 1 Kg | | | 3 | | | |
| Propylene (other) | | | | | | | |
| | | | | | | 0 | |

SimaPro3
Average data for 19 european cracking fascilities producing monomer quality propylene.
taken from:
PWMI/APME, Ecoprofiles of the European plastics industry, 1992-1994
report 2, tbl 36 pg 21

Energy input

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| Coal | MJ/Kg propylene | 0.56 | | 3 | Kg/Kg propylene | 0.020063053 | |
| Oil | MJ/Kg propylene | 1.86 | | 3 | Kg/Kg propylene | 0.041692407 | |
| Natural Gas | MJ/Kg propylene | 6.68 | | 3 | Kg/Kg propylene | 0.145217391 | |
| Hydropower | MJ/Kg propylene | 0.12 | | 3 | MJ/Kg propylene | 0.12 | |
| Fission | MJ/Kg propylene | 0.23 | | 3 | MJ/Kg propylene | 0.23 | |

Probably different mix in US

Material input

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| Oil | MJ/Kg propylene | 36.38 | | 3 | Kg/Kg propylene | 0.81546762 | |
| Natural Gas | MJ/Kg propylene | 23.65 | | 3 | Kg/Kg propylene | 0.514130435 | |
| Coal | MJ/Kg propylene | 0.01 | | 3 | Kg/Kg propylene | 0.000358269 | |
| Iron ore | Kg/Kg propylene | 0.0002 | | 3 | Kg/Kg propylene | 0.0002 | |
| limestone | Kg/Kg propylene | 0.0001 | | 3 | Kg/Kg propylene | 0.0001 | |
| Bauxite | Kg/Kg propylene | 0.0003 | | 3 | Kg/Kg propylene | 0.0003 | |
| Rock salt | Kg/Kg propylene | 0.006 | | 3 | Kg/Kg propylene | 0.006 | |
| Clay | Kg/Kg propylene | 0.00002 | | 3 | Kg/Kg propylene | 0.00002 | |
| Water | Kg/Kg propylene | 1.6 | | 3 | Kg/Kg propylene | 1.6 | |

Output
Air

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| TSP | Kg/Kg propylene | 0.0008 | | | Kg/Kg propylene | 0.0008 | |
| SOx | Kg/Kg propylene | 0.004 | | | Kg/Kg propylene | 0.004 | |
| NOx | Kg/Kg propylene | 0.006 | | | Kg/Kg propylene | 0.006 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| CO | Kg/Kg propylene | 0.0004 | | | Kg/Kg propylene | 0.0004 | |
| CO2 | Kg/Kg propylene | 0.528 | | | Kg/Kg propylene | 0.528 | |
| H2S | Kg/Kg propylene | 0.00001 | | | Kg/Kg propylene | 0.00001 | |
| HCl | Kg/Kg propylene | 0.00001 | | | Kg/Kg propylene | 0.00001 | |
| total HC's | Kg/Kg propylene | 0.008 | | | Kg/Kg propylene | 0.008 | |
| other organic | Kg/Kg propylene | 0.000001 | | | Kg/Kg propylene | 0.000001 | |
| Heavy metals | Kg/Kg propylene | 0.000001 | | | Kg/Kg propylene | 0.000001 | |

Water

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| COD | Kg/Kg propylene | 0.0002 | | | Kg/Kg propylene | 0.0002 | |
| BOD | Kg/Kg propylene | 0.00003 | | | Kg/Kg propylene | 0.00003 | |
| Acid as H+ | Kg/Kg propylene | 0.00004 | | | Kg/Kg propylene | 0.00004 | |
| Metal ions | Kg/Kg propylene | 0.0002 | | | Kg/Kg propylene | 0.0002 | |
| Cl2 | Kg/Kg propylene | 0.00005 | | | Kg/Kg propylene | 0.00005 | |
| Dissolved Organics | Kg/Kg propylene | 0.00002 | | | Kg/Kg propylene | 0.00002 | |
| suspended solids | Kg/Kg propylene | 0.0002 | | | Kg/Kg propylene | 0.0002 | |
| crude oil | Kg/Kg propylene | 0.0001 | | | Kg/Kg propylene | 0.0001 | |
| miscelanious dissolved mater | Kg/Kg propylene | 0.0004 | | | Kg/Kg propylene | 0.0004 | |
| Phenol | Kg/Kg propylene | 0.00007 | | | Kg/Kg propylene | 0.00007 | |

| Solid waste | | | | | | | |
|---|---|---|---|---|---|---|---|
| Production waste (not innert) | Kg/Kg propylene | 0.009 | | | Kg/Kg propylene | 0.009 | |

Sheet End

| Coal type | Moisture % | Sulfur % | %dry | Heat value Btu/lb | Btu/lbdry | | | |
|---|---|---|---|---|---|---|---|---|
| Sub bit C | 26 | 0.3 | 0.41 | 8230 | 11121.622 | | | |
| HV bit A | 2.9 | 0.6 | 0.62 | 14170 | 14593.203 | low sulfur coal heating value | | |
| Sub bit B | 22.2 | 0.5 | 0.64 | 9610 | 12352.185 | | | |
| Brown Coal German - Rh | 55 | 0.3 | 0.67 | 4830 | 10733.333 | | | |
| Sub bit A | 13.9 | 0.6 | 0.70 | 10330 | 11997.677 | SD= | 1295.7751 | 0.1081691 |
| Meta Anthracite | 9 | 0.7 | 0.77 | 10080 | 11076.923 | Avg= | 11979.157 | |
| LV bit | 2.9 | 0.8 | 0.82 | 14400 | 14830.072 | median | | |
| Anthracite | 4.3 | 0.8 | 0.84 | 12880 | 13458.725 | | | |
| Lignite | 36.8 | 0.9 | 1.42 | 7000 | 11075.949 | | | |
| MV bit | 2.4 | 1.5 | 1.54 | 14490 | 14846.311 | | | |
| Semi anthracite | 2.1 | 1.7 | 1.74 | 13700 | 13993.871 | | | |
| HV bit B | 6.7 | 2.6 | 2.79 | 12390 | 13279.743 | | | |
| HV bit C | 15.4 | 2.9 | 3.43 | 10740 | 12695.035 | | | |

bit=Bituminous
V=Volatility
L=low
M=Medium
H=high

Source: Kirk Othmer vol 4 1949

Natural gas

| | Mwt | heat value | Rio Arriba, N | Terrell, Tex | Stanton, Kan | San Juan, NM | Olds Field, A | Cliffside, Texas | | avg | SD (rel) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| mol% | | MJ/M^3 | | | | | | | | | |
| Methane | 16.043 | 37.57 | 96.91 | 45.64 | 67.56 | 77.28 | 52.34 | 65.8 | | | |
| ethane | 30.07 | 65.83 | 1.33 | 0.21 | 6.23 | 11.18 | 0.41 | 3.8 | | | |
| propane | 44.097 | 93.6 | 0.19 | | 3.18 | 5.83 | 0.14 | 1.7 | | | |
| butane | 58.123 | 120.98 | 0.05 | | 1.42 | 2.34 | 0.16 | 0.8 | | | |
| pentane+ | 72.15 | 148.84 | 0.02 | | 0.04 | 1.18 | 0.41 | 0.5 | | | |
| CO2 | 44.01 | 0 | 0.82 | 53.93 | 0.07 | 0.8 | 8.22 | | | | |
| H2S | 34.076 | 23.7 | | 0.01 | | | 35.79 | | | | |
| N2 | 28.013 | 0 | 0.68 | 0.21 | 21.14 | 1.39 | 2.53 | 25.6 | | avg | SD (rel) |
| Mol wt: | | | 16.625849 | 31.182 | 20.921258 | 21.28362 | 25.492892 | 20.445665 | | 19.610242 | 10.79% |
| heating value | MJ/M^3 | | 37.6 | 17.3 | 34.9 | 46.8 | 30 | 30.7 | | 39.766667 | 12.81% |
| | MJ/KG | | 50.658467 | 12.427683 | 37.366777 | 49.254778 | 26.360289 | 33.634514 | | 45.760008 | 13.03% |
| | 0.0224M^3/mol | | | too high CO2 content for use | | | too high Sulfur content | too low heating value(?) | | | |

Source: Kirk Othmer Ed 4 vol 12 1993

MJ/m^3

Heating values for processed city natural gas:
source Perry 6 (1964)
averaged from table 9-14

Btu/scf 1049.5714

Synopsis of table 9-14

| | Mwt | heat value | Baltimore | Columbus | Houston | Burmingham | Washington | Phoenix |
|---|---|---|---|---|---|---|---|---|
| mol% | | MJ/M^3 | Md | Ohio | Tx | Al | DC | Az |
| Methane | 16.043 | 37.57 | 94.4 | 93.14 | 92.5 | 93.14 | 95.15 | 87.37 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| ethane | 30.07 | 65.83 | 3.4 | 3.58 | 4.8 | 2.5 | 2.84 | 8.11 | | |
| propane | 44.097 | 93.6 | 0.6 | 0.66 | 2 | 0.67 | 0.63 | 2.26 | | |
| butane | 58.123 | 120.98 | 0.5 | 0.22 | 0.3 | 0.32 | 0.24 | 0.13 | | |
| pentane+ | 72.15 | 148.84 | 0 | 0.09 | 0 | 0.12 | 0.05 | 0 | | |
| CO2 | 44.01 | 0 | 0.6 | 0.85 | 0.27 | 1.06 | 0.62 | 0.61 | | |
| H2S | 34.076 | 23.7 | | 0.01 | | | | | | |
| N2 | 28.013 | 0 | 0.5 | 0.21 | 21.14 | 2.14 | 0.42 | 1.37 | avg | SD (rel) |
| Mol wt: | | | 17.126294 | 16.939122 | 23.380219 | 17.328208 | 16.9628 | 18.179837 | 18.319413 | 15.84% |
| heating value | MJ/M^3 | | 39.2023 | 38.3444 | 38.4563 | 38.1952 | 38.8666 | 39.9483 | 38.835517 | 1.10% |
| | MJ/KG | | 51.273879 | 50.705967 | 36.844014 | 49.374551 | 51.324771 | 49.221668 | 48.124142 | 13.30% |

0.0224M^3/mol

Phosphorous trichloride production from Phosphorous and chlorine.

| | Mwt | DHfo | | Cpo | | |
|---|---|---|---|---|---|---|
| | kg/mol | kcal/mol | MJ/Kg | Cal/deg mo | MJ/Kg deg | |
| P4 | 123.8952 | 14.08 | 0.475488 | 16.05 | 0.54202 | as gas |
| PCl3 | 137.3328 | -76.4 | -2.327613 | 17.17 | 0.5231 | as gas |
| Cl2 | 70.906 | 0 | 0 | 8.104 | 0.4782 | |
| water | 18.0153 | | | 17.995 | 4.17929 | |
| | | reaction | | | | |
| | 137.3328 | 79.92 | 2.434854 | | | |
| | | | | | | |
| yield | 0.95 | relative to reactants | | | | |
| reflux ratio | 0.5 | | | | | |

Module — Material (Kg/Kg phosphoroustrichloride) and Energy in MJ/Kg phosphoroustrichloride

| Module | Phosphorous | Chlorine | Cooling water | | PCl3 | | Fuel ? | Electricity | Energy loss | Reaction | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Reactor | 0.308631 | 0.855984 | | | 1.1119838 | -2.223968 | | | | | 0.0526316 |
| | 0 | 0 | | | 37.809375 | -87.2524 | | | | 2.4348537 | -47.00817 |
| | 25 | 25 | | | 90 | 100 | | | | | |
| Reflux cooler | | | | | 2.2239675 | -2.223968 | | | | | 0 |
| | | | | | 87.252403 | -75.61875 | | | | | 11.633654 |
| | | | | | 100 | 90 | | | | | |
| Condenser | | | | | 1.1119838 | -1.111984 | | | | | 0 |
| | | | | | 49.443028 | -37.80937 | | | | | 11.633654 |
| | | | | | 100 | 90 | | | | | |
| Still | -0.071223 | -0.040761 | | | 1.1119838 | -1 | | | | | -1.11E-16 |
| | -1.93019 | -0.974596 | | | 37.809375 | -26.15518 | | | | | 8.7494095 |
| | 75 | 75 | | | 90 | 75 | | | | | |
| | 0.237409 | 0.815223 | 0 | 0 | -1 | -6.559919 | 0 | 0 | 0 | 0 | 0.0526316 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| -1.93019 | -0.974596 | 0 | 0 | -14.52153 | 0 | 0 | 0 | 2.4348537 |

| | | |
|---|---|---|
| | Cooling water | |
| | 25 | deg C temp rise |
| | 104.482135 | heat removal MJ/kg water |
| | 2.43485373 | MJ/kg product |
| c water | 0.02330402 | Kg/Kg product |

7.8726E-05 kJ Elec/Kg Based on viscosity and density of water for a 250 ft static head per pumping stage in 40hr week & 52 week year daytime operation. multiply by specific gravity of material and relative viscosity to that of water.

| | | representati | Sp grav | Sp visc | kgflow/kg prod | | |
|---|---|---|---|---|---|---|---|
| storage | to reactor | P4 | 1.745 | 2 | 0.237409 | 1.9E-08 | viscosity is a guess |
| reflux | to reactor | PCl3 | 1.575 | 2 | 1.111984 | 8.8E-08 | viscosity is a guess |
| reflux | to condenser | PCl3 | 1.575 | 2 | 1.111984 | 8.8E-08 | |
| condenser | to still | PCl3 | 1.575 | 2 | 1.111984 | 8.8E-08 | |
| recycle | to reactor | P4 | 1.745 | 2 | 0.071223 | 5.6E-09 | |
| cooling water | | | 1 | 1 | 0.023304 | 1.8E-09 | |
| | | | | | | 2.9E-07 | total pumping energy per kg prod |

Acetic Anhydride synthesis
Source: all process data

Technical report HDC-125-95 Pg 8
By Laurie J. Brown
Holston Defense Corporation
Subsidiary of Eastman Chemical Co.
Kingsport, TN 37660

New heat source from NG changes coal tar, cinder and Flue gas data.
Final calculation based on producer gas required to consume the air supplied to the process.
The heat value for the producer gas is matched with standard NG, from which air requirements are taken.

Physical data are taken from:
Perry's Chemical Engineer's Handbook, Ed 6
McGraw-Hill, 1984

Kirk-Othmer Encyclopaedia of chemical technology, Ed 2, Ed 4
Wiley Interscience, 1966, 1994
Entries: Gas, Manufactured; Gas, Natural; Coal; Coal tar

| Product | | | Conc. | Raw data in lb | kg per kg AcAnhd solution | kg per kg AcAnhd dry base | |
|---|---|---|---|---|---|---|---|
| | | AcAnhd | 0.975 | 2.03 | 1 | 1 | |
| | | (Water) | 0.025 | | | 0.025641 | |
| | | Total | | 2.03 | 1 | 1.025641 | |
| Output | | | | | | | |
| scrub | to IWTF | AcOH | 0.005 | 0.08455 | 0.0416502 | 0.0427182 | |
| | | W | as pure | 0.0841273 | 0.041442 | 0.0425046 | |
| | | AcOH | as pure | 0.0004228 | 0.0002083 | 0.0002136 | |
| mill washout to IWTF | | | | 0.2146 | 0.1057143 | 0.1084249 | |
| | | W | 0.99 | 0.212454 | 0.1046571 | 0.1073407 | |
| | | AcOH | 0.01 | 0.002146 | 0.0010571 | 0.0010842 | |
| Condensate to IWTF | | | | 0.06039 | 0.0297488 | 0.0305116 | |
| | | AcOH/W | trace | 0 | 0 | 0 | |
| | | Water | | 0.06039 | 0.0297488 | 0.0305116 | |
| condensate to steam plant A | | | | 5.987 | 2.9492611 | 3.0248832 | |
| cinders to block plant | | | | 0.2186 | 0.1076847 | 0.1104459 | Replaced system |
| | | | | 0 | 0 | 0 | NG system |
| Producer gas manufacture Coal tar to steam plant A | | | | | | | |
| | | Coal tar | | 0.06779 | 0.0333941 | 0.0342503 | |
| | | | | 0 | 0 | 0 | NG system |
| Evaporator sludge from ketene gas manufacture | | | | 0.04026 | 0.0198325 | 0.020341 | |
| | to Bldg 2 | AcOH | 0.9 | 0.036234 | 0.0178493 | 0.0183069 | |
| | | W | 0.1 | 0.004026 | 0.0019833 | 0.0020341 | |
| Scrubber underflow to Bldg 2 | | | | 0.1208 | 0.0595074 | 0.0610332 | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | AcOH | | 0.12 | 0.014496 | 0.0071409 | 0.007324 | | |
| | | W | | 0.88 | 0.106304 | 0.0523665 | 0.0537092 | | |
| Refining residue to Bldg 2 | | | | | | | | | |
| | | AcOH | pure | | 0.3759 | 0.1851724 | 0.1899204 | | |
| Ball mill sludge to Steam Plant B | | | | | 0.004828 | 0.0023783 | 0.0024393 | | |
| Inputs | | | | | | | | | |
| | Materials | | | | | | | | |
| | | AcOH | | 0.997 | 2.884 | 1.4206897 | 1.4571176 | | |
| | | NH3 | | | 0.0005629 | 0.0002773 | 0.0002844 | | |
| | | Eth3PO4 | | | 0.00856 | 0.0042167 | 0.0043249 | | |
| | Heat source | Air | | | 0.5865 | 0.2889163 | 0.2963244 | | |
| | changed | Coal | | | 0.6795 | 0.3347291 | 0.3433119 | | Energy |
| | Replacement | Air | | | 0.4979873 | 0.2453139 | 0.251604 | | |
| | System | Natural Gas | | | 0.0300438 | 0.0147999 | 0.0151794 | | |
| | | EthGlycol | | | 5.306E-05 | 2.614E-05 | 2.681E-05 | | |
| | | Freon | | | 5.383E-06 | 2.652E-06 | 2.72E-06 | | |
| | | Filtered Water | | | 13.14 | 6.4729064 | 6.6388784 | | |
| | | Steam | | | 15.03 | 7.4039409 | 7.5937855 | | |
| | | River Water | | | 1590 | 783.25123 | 803.3346 | | |
| | Energy | | | | | | | | |
| | | Electricity | kWhr | | 0.1122 | 0.0552709 | 0.0566881 | | |
| Waste | | | | | | | | | |
| | Water/condensate return to river (Non-contact) | | | | 1603 | 789.65517 | 809.90274 | | |
| | Steam Condensate to river (Non-contact) | | | | 8981 | 4424.1379 | 4537.5774 | | |
| Air Emiossion | | | | | | | | | |
| | | AcOH | | | 0.0618 | 0.0304433 | 0.0312239 | | |
| | Replaced | Flue Gas | | | 0.9797 | 0.4826108 | 0.4949855 | | |
| | Replacement system | Flue gas | | | 0.5280311 | 0.2601138 | 0.2667834 | | |
| | | Freon | | | 5.383E-06 | 2.652E-06 | 2.72E-06 | | |
| | | | | | lb per lb RDX base | kg per kgAcAnmix | kg per kgAcAn pure | | |
| | | Coal | | | 0.6795 | 0.3347291 | 0.3433119 | | |
| | | tar | | | 0.06779 | 0.0333941 | 0.0342503 | 0.099764533 10% tar | |
| | | Producer gas | | | 0.4275059 | 0.192794 | 0.1331015 | difference from coal and (tar+cinder) | 70% gas |
| | | Heating value | Btu | | 4109.6485 | 2024.4574 | 2076.3666 | | |
| | | air required | | | 0.675477 | 0.3327473 | 0.3412793 | | |
| This calculation method came up with inconsistent results | | NG replacement nescf | | | 3.9155492 | 1.928842 | 1.9782994 | to equal heating values | |
| | | | | | 0.1904544 | 0.0938199 | 0.0962255 | | |
| | | Air required | | | 3.1568477 | 1.5550974 | 1.5949717 | | |
| | | Air | | | 0.5865 | 0.2889163 | 0.2963244 | | |
| | | Producer gas | | | 0.2554196 | 0.1258225 | 0.1290487 | calculated according to air supply | |
| | | Heating value | btu | | 648.28993 | 319.35464 | 327.54323 | calc according to heat of gas combustion | |
| Final calculation method | | NG replacement nescf | | | 0.6226572 | 0.3067277 | 0.3145925 | heat value to equal heating values | |

| | | | |
|---|---|---|---|
| | 0.0300438 | 0.0147999 | 0.0151794 |
| Air required | 0.4979873 | 0.2453139 | 0.251604 |
| | 1.0140059 | 0.4817102 | 0.4294258 |
| Cinder | 0.2186 | 0.1076847 | 0.1104459 |
| Flue gas | 0.9797 | 0.4826108 | 0.4949855 |
| | 1.1983 | 0.5902956 | 0.6054314 |

Mass balance error -15.38% is missing output, perhaps to scrubing

Heating values for processed city natural gas:
source Perry 6 (1964)
averaged from table 9-14

| | |
|---|---|
| Btu/scf | 1049.571429 |
| MJ/M^3 | 39.14901429 |
| MJ/Kg | 50.18997432 |

Manufactured gas
Data from KO 2 (1964) for "modern mechanical method"

| | Moisture | Heating valueBtu/lb | | Gas yield scf/ton | | gas lb/lb coal | Gross heat value Btu/scf (gas heat value) | | Btu/ton coal | Btu/lb coal | Tar yield gal/ton (Tar data) | | lb/lbcoal | energy value | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | wet | dry | wet base | dry base | | wet base | dry base | wet base | wet base | wet base | dry base | wet | btu in tar/lb coal | |
| Anthracite | 0.051 | 10800 | 11380.4 | 123900 | 130558.48 | | 138 | 145.41623 | 17098200 | 8549.1 | 9.5 | 10.010537 | 0.0475688 | 810 | 17027.962 |
| Belgian Coal | 0.026 | 11980 | 12299.795 | 120900 | 124127.31 | | 150 | 154.00411 | 18135000 | 9067.5 | 1 | 1.026694 | 0.0050072 | 83.86 | 16747.737 |
| Baddesley | 0.05 | 12080 | 12715.789 | 116100 | 122210.53 | | 165.6 | 174.31579 | 19226160 | 9613.08 | 21 | 22.105263 | 0.1051521 | 1679.12 | 15968.485 |

Btu/lb tar
16.5
Characteristic value

On the basis of 10% tar production in the process the Baddesley type coal is used
This coal then provides 9613.08 gas heating value in Btu/lb coal

Baddesley coal ga

| composition | MWt | vol% | O2 per mole | mol O2 per mol gas | | | |
|---|---|---|---|---|---|---|---|
| CO2 | 44.01 | 6.7 | 0 | 0 | | | |
| alkyls | | | | | | | |
| O2 | 31.9988 | 0 | 0 | 0 | | | |
| CO | 28.016 | 25.3 | 0.5 | 0.1265 | | | |
| H2 | 2.0158 | 21 | 0.5 | 0.105 | | | |
| CH4 | 16.043 | 1.8 | 2 | 0.036 | | | |
| N2 | 28.013 | 45.2 | 0 | 0 | | 0.578863788 | mol air producing mol gas |
| Gas Mwt | 23.410686 | | | 0.2675 | mol O2 per mol gas | 1.277093478 | mol air to burn mol gas |
| | | | | 0.3656313 | kg O2 per Kg gas | 1.855957266 | mol air used/mol gas |
| | | | | 1.5800413 | kgair/kg gas | 2.296221153 | kg air used / kg gas |

ideal gas density of producer gas
1.045119911 kg/m^3
0.065244718 lb/cuf

physical data

| | | | |
|---|---|---|---|
| Density of Tar | 75 | lb/cuf | Perry 6 (1984) |
| | 1200 | kg/m^3 | |
| | 10.01448763 | lb/gal | |

Units
scf is volume in cubic feet at 60 Farenheit and 30" Hg — KO 2 (1964)

| density | lb/cuf | lb/gal | kg/m^3 | Perry 6 (1984) |
|---|---|---|---|---|
| | 0.062427974 | 0.008345406 | 1 | |
| | 7.480519351 | 1 | 119.8264 | |
| | 1 | 0.133680558 | 16.01846 | |

| mass | ton (short - US) | lb | kg | Perry 6 (1984) |
|---|---|---|---|---|
| | 1 | 2000 | | |
| | | 2.204622962 | 1 | |

| Pressure | "Hg | N/m^2 | atm | psia | Perry 6 (1984) |
|---|---|---|---|---|---|
| | 1 | 3376.9 | 0.0333274 | 0.4897749 | |
| | 2.041754272 | 6894.8 | 0.0680464 | 1 | |
| | 30.00533033 | 101325 | 1 | 14.695858 | |
| | | 1 | | | |

| Heat value | MJ/m^3 | btu/scf | | Perry 6 (1984) |
|---|---|---|---|---|
| | 0.0373 | | 1 | |
| Energy | MJ | Btu | | Perry 6 (1984) for steam table values |
| | 0.00105504 | | 1 | |

| molar dry air composition | | Mwt | mass compo | kg air per kg component |
|---|---|---|---|---|
| N2 | 0.78084 | 28.0134 | 0.7552105 | 1.3241342 |
| O2 | 0.20946 | 31.9988 | 0.2314062 | 4.3214062 |
| CO2 | 0.00033 | 44.01 | 0.0005014 | 1994.3188 |
| Ar | 0.00934 | 39.948 | 0.012882 | 77.627923 |
| total | 0.99997 | 28.96409 | 1 | |

Perry 6 (1984)

Synopsis of table 9-14

| mol% | Mwt | heat value MJ/M^3 | Baltimore Md | Columbus Ohio | Houston Tx | Burmingham Al | Washington DC | Phoenix Az | average | molecular O2 demand per molecule | kg O2 demand per kg gas |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Methane | 16.043 | 37.57 | 94.4 | 93.14 | 92.5 | 93.14 | 95.15 | 87.37 | 92.616667 | 2 | 3.4185467 |
| ethane | 30.07 | 65.83 | 3.4 | 3.58 | 4.8 | 2.5 | 2.84 | 8.11 | 4.205 | 3.5 | 0.2716167 |
| propane | 44.097 | 93.6 | 0.6 | 0.66 | 2 | 0.67 | 0.63 | 2.26 | 1.1366667 | 5 | 0.1048879 |
| butane | 58.123 | 120.98 | 0.5 | 0.22 | 0.3 | 0.32 | 0.24 | 0.13 | 0.285 | 6.5 | 0.0341885 |
| pentane+ | 72.15 | 148.84 | 0 | 0.09 | 0 | 0.12 | 0.05 | 0 | 0.0433333 | 8 | 0.0063979 |
| CO2 | 44.01 | 0 | 0.6 | 0.85 | 0.27 | 1.06 | 0.62 | 0.61 | 0.6683333 | | Total |
| H2S | 34.076 | 23.7 | | 0.01 | | | | | | | 3.8356377 |
| N2 | 28.013 | 0 | 0.5 | 0.21 | 0.13 | 2.14 | 0.42 | 1.37 | 0.795 | SD (rel) | |
| Mol wt: | | | 17.126294 | 16.939122 | 17.494688 | 17.328208 | 16.9628004 | 18.179837 | 17.338492 | 2.26% | kg air demand |
| heating value | MJ/M^3 | | 39.2023 | 38.3444 | 38.4563 | 38.1952 | 38.8666 | 39.9483 | 38.835517 | 1.43% | per kg gas |
| | MJ/KG | | 51.273879 | 50.705967 | 49.23901 | 49.374551 | 51.32477064 | 49.221668 | 50.189974 | 1.72% | 16.575349 |
| | Btu/scf | | 1051 | 1028 | 1031 | 1024 | 1042 | 1071 | 1041.1667 | | |
| | 0.0224M^3/mol | | | | | | | | | | |
| | | | | 288.70556 | 60 F | | | | | | |

| | Carbons | Hydrogen | average oxygen demand |
|---|---|---|---|
| Methane | 1 | 4 | |
| ethane | 2 | 6 | |
| propane | 3 | 8 | |
| butane | 4 | 10 | |
| pentane+ | 5 | 12 | |

Acetic acid for Acetic Anhydride synthesis
Concentration of the acid
Source: for all data
Technical report HDC-125-95 Pg 6
By Laurie J. Brown
Holston Defense Corporation
Subsidiary of Eastman Chemical Co.
Kingsport, TN 37660

| | | | Conc. | Raw data in lb | kg per kg Acetic acid solution | kg per kg Acetic acid dry base |
|---|---|---|---|---|---|---|
| Product | | | | | | |
| | | | | 3.935 | 1 | 1.003009 |
| | | AcOH | 0.997 | 3.923195 | 0.997 | 1 |
| | | (Water) | 0.003 | 0.011805 | 0.003 | 0.003009 |
| Output | | | | | | |
| Slopwater from flashing | | | | 6.652 | 1.6904701 | 1.6955568 |
| | to IWTF | AcOH | 0.05 | 0.3326 | 0.0845235 | 0.0847778 |
| | | W | 0.95 | 6.3194 | 1.6059466 | 1.610779 |
| Low Boilers from flashing n-PropylOAc purification | | | | | | |
| | to IWTF | | | 0.2146 | 0.0545362 | 0.0547003 |
| | | Propylformate | | | | |
| | | MeOAc | | | | |
| | | Acetone | | | | |
| | | MeNO3 | | | | |
| | | EthOAc | | | | |
| Sludge from sludge heater | | | | 0.02825 | 0.0071792 | 0.0072008 |
| | to IWTF | AcOH | 0.1 | 0.002825 | 0.0007179 | 0.0007201 |
| | | Water | 0.9 | 0.025425 | 0.0064612 | 0.0064807 |
| | | High b.p. materials | | | | |
| condensate to steam plant A | | | | 6.264 | | |

Inputs

Materials

| | | | | | | |
|---|---|---|---|---|---|---|
| | AcOH | total | | 3.978647 | 1.011092 | 1.0141344 |
| Recover acid | AcOH | | 0.593 | 5.884 | 1.4952986 | 1.499798 |
| AcAnhd recycle | AcOH | | 0.795 | 0.537 | 0.1364676 | 0.1368782 |
| Fresh from Malinkrodt | AcOH | | 0.2 | 0.3126 | 0.0794409 | 0.07968 |
| | Water in solution | total | | 2.754953 | 0.7001151 | 0.7022218 |
| | n-PropylOAc | | | 0.01036 | 0.0026328 | 0.0026407 |
| | N2 | | | 0.01553 | 0.0039466 | 0.0039585 |
| | Filtered Water | | | 6.532 | 1.6599746 | 1.6649695 |
| | Steam | | | 15.66 | 3.9796696 | 3.9916446 |
| | River Water | | | 77.39 | 19.66709 | 19.726269 |
| Energy | | | | | | |
| | Electricity | kWhr | | 0.02044 | 0.0051944 | 0.00521 |
| Waste | | | | | | |
| Water return to river (Non-contact) | | | | 77.39 | 19.66709 | 19.726269 |
| Steam Condensate to river (Non-contact) | | | | 9.395 | 2.3875476 | 2.3947318 |
| Air Emiossion | | | | | | |
| | AcOH | | | 0.004242 | 0.001078 | 0.0010813 |
| | n-PropylOAc | | | 0.003653 | 0.0009283 | 0.0009311 |
| | N2 | | | 0.01553 | 0.0039466 | 0.0039585 |

Acetic acid for Acetic Anhydride synthesis
Purification of spent acid
Source: for all data
Technical report HDC-125-95 Pg 18
By Laurie J. Brown
Holston Defense Corporation
Subsidiary of Eastman Chemical Co.
Kingsport, TN 37660

| | | | Conc. | Raw data in lb | kg per kg Acetic acid solution | kg per kg Acetic acid dry base |
|---|---|---|---|---|---|---|
| Product | | | | | | |
| | | | | 5.884 | 1 | 1.6666667 |
| | | AcOH | 0.6 | 3.5304 | 0.6 | 1 |
| | | (Water) | 0.4 | 2.3536 | 0.4 | 0.6666667 |
| Output | | | | | | |
| Condensate | | | | 0.09333 | 0.0158617 | 0.0264361 |
| | to IWTF | AcOH | 0.02 | 0.0018666 | 0.0003172 | 0.0005287 |
| | | W | 0.98 | 0.0914634 | 0.0155444 | 0.0259074 |
| Explosive Slurry | | | | 0.4527 | 0.0769375 | 0.1282291 |
| | to ??? | AcOH | 0.372 | 0.1684044 | 0.0286207 | 0.0477012 |
| | | Water | 0.353 | 0.1598031 | 0.0271589 | 0.0452649 |
| | | Salts | 0.176 | 0.0796752 | 0.013541 | 0.0225683 |
| | | Explosive | 0.099 | 0.0448173 | 0.0076168 | 0.0126947 |
| ANG-77 mix | | | | 0.3733 | 0.0634432 | 0.1057387 |
| | to ??? | Nitrates of Am | 0.74 | 0.276242 | 0.046948 | 0.0782467 |
| | | Water | 0.242 | 0.0903386 | 0.0153533 | 0.0255888 |
| | | AcOH | 0.005 | 0.0018665 | 0.0003172 | 0.0005287 |
| | | Explosive | 0.01 | 0.003733 | 0.0006344 | 0.0010574 |
| | | Gum | 0.003 | 0.0011199 | 0.0001903 | 0.0003172 |
| Inputs | | | | | | |
| | Materials | | | | | |
| | Spent Acid | | total | 6.073 | 1.032121 | 1.7202017 |
| | | AcOH | 0.603 | 3.662019 | 0.622369 | 1.0372816 |
| | | HNO3 salts | 0.056 | 0.340088 | 0.0577988 | 0.0963313 |
| | | explosives | 0.008 | 0.048584 | 0.008257 | 0.0137616 |
| | | Water in solu | 0.333 | 2.022309 | 0.3436963 | 0.5728272 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | NH3 | | 0.01639 | 0.0027855 | 0.0046425 |
| | | Explosive (RDX) | | 5.075E-05 | 8.625E-06 | 1.438E-05 |
| | | Gum | | 0.00112 | 0.0001903 | 0.0003172 |
| | | Filtered Water | | 0.02818 | 0.0047893 | 0.0079821 |
| | | Steam | | 4.68 | 0.7953773 | 1.3256288 |
| | | River Water | | 62.7 | 10.656016 | 17.760027 |
| | Energy | | | | | |
| | | Electricity | kWhr | 0.05474 | 0.0093032 | 0.0155053 |
| Waste | | | | | | |
| | Water return to river (Non-contact) | | | 62.7 | 10.656016 | 17.760027 |
| | Steam Condensate to river (Non-contact) | | | 3.991 | 0.6782801 | 1.1304668 |
| Air Emiossion | | | | | | |
| | | AcOH | | 0.004242 | 0.0007209 | 0.0012016 |
| | | n-PropylOAc | | 0.003653 | 0.0006208 | 0.0010347 |
| | | N2 | | 0.01553 | 0.0026394 | 0.0043989 |

Acetic acid treatment and Acetic Anhydride synthesis
Area A Steam Plant
Source: for all data
Technical report HDC-125-95 Pg 24
By Laurie J. Brown
Holston Defense Corporation
Subsidiary of Eastman Chemical Co.
Kingsport, TN 37660

| | | | Conc. | Raw data in lb | kg per kg Steam | kg per kg Steam | |
|---|---|---|---|---|---|---|---|
| Product | | | | | | | |
| | | Steam | | 31.07 | 1 | 1 | |
| | | | | | | 0.8858407 | weighted according to coal utilization |
| Output | | | | | | | |
| To Block Plant | | Cinders | | 0.2619 | 0.0084294 | 0.0074671 | |
| | | Fly Ash | | 0.04937 | 0.001589 | 0.0014076 | |
| to IWTF | | Boiler blowdown | | 0.777 | 0.025008 | 0.0221531 | |
| | with: | Phosphates | | | | | |
| | | Sulfates | | | | | |
| | | Sulfites | | | | | |
| | | Cooling Water | | 5.413 | 0.1742195 | 0.1543307 | |
| | with: | fly ash | | | | | |
| | | cinders | | | | | |
| Inputs | | | | | | | |
| | Materials | | | | | | |
| 1992 | Old numbers | Coal | | 3.182 | 0.1024139 | 0.0907224 | |
| | | Coal Tar | | 0.06779 | 0.0021818 | 0.0019328 | Eliminated due to replacement of Coal producer gas by NG |
| 1995 | Updated | Coal | | 3.2313018 | 0.1040007 | 0.0921281 | Sufficient coal to replace Coal tar heating value |
| | | Air | | 44.55 | 1.433859 | 1.2701707 | Assumed to remain the same due to similar H and C balance in Coal and tar |
| | | Boiler water | | 19.42 | 0.6250402 | 0.5536861 | |
| | | Condensate | | 12.43 | 0.4000644 | 0.3543933 | |
| | | Filtered Water | | 1.624 | 0.0522691 | 0.0463021 | |
| | | River Water | | 3.789 | 0.1219504 | 0.1080287 | |
| | | Disodium Phosphate | | 4.922E-05 | 1.584E-06 | 1.403E-06 | |
| | | Sodium Sulfite | | 2.538E-05 | 8.169E-07 | 7.236E-07 | |
| | Energy | | | | | | |
| | | Electricity | kWhr | 0.04629 | 0.0014899 | 0.0013198 | |
| Waste | | | | | | | |
| | | Fly Ash to Landfill | | 0.2045 | 0.0065819 | 0.0058305 | |
| Air Emiossion | | | | | | | |
| | | VOCs | | 7.921E-05 | 2.549E-06 | 2.258E-06 | |
| | | NOx | | 0.02179 | 0.0007013 | 0.0006213 | |
| | | CO | | 0.007954 | 0.000256 | 0.0002268 | |

| | | | |
|---|---|---|---|
| SOx | 0.06045 | 0.0019456 | 0.0017235 |
| Particulates | 0.0007636 | 2.458E-05 | 2.177E-05 |
| Flue gas | 47.19 | 1.5188285 | 1.3454401 |

Data from KO 2 (1964) for "modern mechanical method"

| | Moisture | Heating value Btu/lb wet | Heating value Btu/lb dry | Gas yield scf/ton wet base | Gas yield scf/ton dry base | gas lb/lb coal | Gross heat value wet base | gas heat value Btu/scf dry base | Btu/ton coal wet base | Btu/lb coal wet base | Tar yield gal/ton wet base | Tar yield gal/ton dry base | lb/lbcoal wet | energy value btu in tar/lb coal | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Anthracite | 0.051 | 10800 | 11380.4 | 123900 | 130558.48 | | 138 | 145.41623 | 17098200 | 8549.1 | 9.5 | 10.010537 | 0.0475688 | 810 | 17027.962 |
| Belgian Coa | 0.026 | 11980 | 12299.795 | 120900 | 124127.31 | | 150 | 154.00411 | 18135000 | 9067.5 | 1 | 1.026694 | 0.0050072 | 83.86 | 16747.737 |
| Baddesley | 0.05 | 12080 | 12715.789 | 116100 | 122210.53 | | 165.6 | 174.31579 | 19226160 | 9613.08 | 21 | 22.105263 | 0.1051521 | 1679.12 | 15968.485 |
| | | | | | | | | | | | | | | | Btu/lb tar |
| | | | | | | | | | | | | | | | 16500 |
| | | | | | | | | | | | | | | | Characteristic value |

Wet Coal heating value
taken as 12000 Btu/lb

Kentucky - Tenn - Ohio Coals
typically 14000 Btu/lb ASTM "Moist"

Coal utilization breakdown for by product distribution

| | | lb/lb RDX | |
|---|---|---|---|
| Coal | Coal | 3.182 | |
| | Cinders | 0.2619 | |
| | Ash | 0.25387 | |
| | Energy coal | 2.66623 | 88.58% |
| | Cinder Coal | 0.3436 | 11.42% |
| | Utilized coal | 3.00983 | 100.00% |

Acetic acid treatment and Acetic Anhydride synthesis
Area A Water filtration
Source: for all data
Technical report HDC-125-95 Pg 28
By Laurie J. Brown
Holston Defense Corporation
Subsidiary of Eastman Chemical Co.
Kingsport, TN 37660

| | | | Conc. | Raw data in lb | kg per kg Filtered wate | kg per kg Boiler water | kg per kg Filtered wate | kg per kg Boiler water | |
|---|---|---|---|---|---|---|---|---|---|
| Product | | | | | | | | | |
| | | Filtered water | | 130.8 | 1 | 6.7353244 | 1 | 0.8707229 | |
| | | Boiler Water | | 19.42 | 0.1484709 | 1 | 0.1292771 | 1 | |
| | | | | 150.22 | | | 0.8707229 | 0.1292771 | |
| Output | | | | | | | | | |
| to IWTF | | Water | | 0.6891 | 0.0052683 | 0.035484 | 0.0045873 | 0.0006811 | 0.0052683 |
| | with: | Alum | | 0.02785 | 0.0002129 | 0.0014341 | 0.0001854 | 2.753E-05 | |
| | | Ion exchange regeneration | | 1.426 | 0.0109021 | 0.0734295 | 0.0094927 | 0.0014094 | |
| | with: | H2SO4 | | | | | | | |
| | | CaSO4 | | | | | | | |
| | | MgSO4 | | | | | | | |
| | | NaCl | | | | | | | |
| | | CaCl2 | | | | | | | |
| | | MgCl2 | | | | | | | |
| Inputs | | | | | | | | | |
| | Materials | | | | | | | | |
| | | River water | | 304 | 2.324159 | 15.653965 | 2.0236986 | 0.3004604 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Hydrated lime | | 7.229E-05 | 5.527E-07 | 3.722E-06 | 4.812E-07 | 7.145E-08 |
| | Al Sulfate | | 0.002363 | 1.807E-05 | 0.0001217 | 1.573E-05 | 2.335E-06 |
| | Cl2 | | 3.999E-05 | 3.057E-07 | 2.059E-06 | 2.662E-07 | 3.952E-08 |
| | H2SO4 | | 0.003582 | 2.739E-05 | 0.0001844 | 2.385E-05 | 3.54E-06 |
| | Rock Salt | | 0.002891 | 2.21E-05 | 0.0001489 | 1.925E-05 | 2.857E-06 |
| Energy | | | | | | | |
| | Electricity | kWhr | 0.1569 | 0.0011995 | 0.0080793 | 0.0010445 | 0.0001551 |
| Waste | | | | | | | |
| Air Emiossion | | | | | | | |

Industrial Wastewater Treatment Facility
Both areas
Source: for all data
Technical report HDC-125-95 Pg 32
By Laurie J. Brown
Holston Defense Corporation
Subsidiary of Eastman Chemical Co.
Kingsport, TN 37660

| | | | Conc. | Raw data in lb | kg per kg wastewater | |
|---|---|---|---|---|---|---|
| Product | | | | | | |
| Output | | | | | | |
| Inputs | | | | | | |
| | Materials | | | | | |
| IWTF streams | | Wastewater | | 329.5 | 1 | |
| | | NaOH 20% | | 0.0314 | 9.53E-05 | |
| | | NaOH | 0.2 | 0.00628 | 1.906E-05 | |
| | | water | 0.8 | 0.02512 | 7.624E-05 | |
| | | Quicklime | | 0.002363 | 7.171E-06 | |
| | | FeCl2 25-35% | | 0.01109 | 3.366E-05 | |
| | | FeCl2 | 0.3 | 0.003327 | 1.01E-05 | |
| | | water | 0.7 | 0.007763 | 2.356E-05 | |
| | | HCl 33% | | 0.0002453 | 7.445E-07 | |
| | | HCl | 0.33 | 8.095E-05 | 2.457E-07 | |
| | | water | 0.67 | 0.0001644 | 4.988E-07 | |
| | | Magnifloc 496 | | 3.691E-05 | 1.12E-07 | flocculant |
| | | Filtered water | | 14.96 | 0.0454021 | |
| | Energy | | | | | |
| | | Electricity | kWhr | 0.2042 | 0.0006197 | |
| Waste | | | | | | |
| | | Treated Industrial waste water | | 344.3 | 1.0449165 | |
| | landfill | Biological sludge | | 0.1533 | 0.0004653 | |
| | landfill | Alum Sludge | | 0.1154 | 0.0003502 | |

Sheet Title: Acetic Acid (for input at 20% concentration into Holston facility)

Sheet Description: Engineering calculation (rough)
This page calculates the vendor emissions from a plant producing Acetic acid.
Not included are raw material production or extraction or water and energy use.
(Energy balance is assumed to be close to 0 due to exothermic producer gas synthesis process)

References/Citations:

Faith Keyes and Clarke's Industrial Chemicals
By F. A. Lowenheim, M. K. Moran
Wiley Interscience, 1975

Perry's Chemical Engineers' Handbook, 6th ed.
McGraw Hill, 1984

AP 42 Ed 4 (1985)
US EPA

Kirk Othmer Encyclopaedia of Chemical Technology
2nd ED, 1964 and 4th Ed, 1991-4
Wiley Interscience,

CRC Handbook of Chemistry and Physics, 66th Edition

Summary Output

Co-product Allocation Calculations

| Co-product | Quantity | Units |
|---|---|---|
| Acetic acid | 1.00E+00 | kg |
| Coal Tar | 1.05E-01 | Kg |
| Total | 1.10515212 | Kg |

Notes: Bbl eq. are calculated on a energy content basis and used to calcualte the allocated LCI emissions factors. Bbl. of CrO production are scaled by multiplying by the ratio of bbl eq. CrO produced to bbl CrO produced.

| LCI components | Unallocated Units | Quantity | Std. Dev. | Allocated Units | Quantity | Std. Dev. | DQI |
|---|---|---|---|---|---|---|---|
| Air | | | | | | | |
| TSP | Kg/Kg Acetic a | 0.0085 | | Kg/Kg Acetic a | 0.007691249 | | 3 |
| SOx | Kg/Kg Acetic a | 0.01865878 | | Kg/Kg Acetic a | 0.016883452 | | 3 |
| CO | Kg/Kg Acetic a | 0.04618681 | | Kg/Kg Acetic a | 0.041792268 | | 3 |
| CO2 | Kg/Kg Acetic a | 0.11356324 | | Kg/Kg Acetic a | 0.102758018 | | 3 |
| total HC's | Kg/Kg Acetic a | 0.03426683 | | Kg/Kg Acetic a | 0.031006436 | | 3 |
| Water | | | | | | | |

| | | | | |
|---|---|---|---|---|
| Production waste | Kg/Kg Acetic a | 0.03599021 | | |

Resource Consumption

| | | | | |
|---|---|---|---|---|
| Coal | Kg/Kg Acetic a | 0.47330006 | Kg/Kg Acetic a | 0.428266893 |
| Methanol | Kg/Kg Acetic a | 0.5367573 | Kg/Kg Acetic a | 0.485686352 |

Notes: This section is where the project specfic calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors

| Unit from | Unit to | Multiplier | Reference | |
|---|---|---|---|---|
| BTU | J | 1055.056 | CRC, 66th Edition | |
| Wh | J | 3600 | CRC, 66th Edition | |
| bbl CrO | BTU CrO | 5800000 | Chemical Engineers' Handbook, 6th ed. | |
| bbl | gal | 42 | Chemical Engineers' Handbook, 6th ed. | |
| gal diesel | BTU diesel | 118500 | Chemical Engineers' Handbook, 6th ed., Figure 9-4 @ S.G. = .76 and sulfur = 0.5% | |
| gal | L | 3.785412 | CRC, 66th Edition | |
| kg | lb | 2.2046226 | CRC, 66th Edition | |
| yr | day | 365 | | |
| m^3 | bbl (petroleum) | 6.289811 | CRC, 66th Edition | |
| gal CrO | lb CrO | 7.2 | | |
| ton | lb | 2000 | | |
| gal fuel oil | BTU fuel oil | 138000 | | |
| cu. ft NG | BTU NG | 1032 | Chemical Engineers' Handbook, 6th ed. | |
| lb Coal (dry | BTU Coal | 12000 | calculation page B | SD=11% |
| kg NG | MJ NG | 46 | Calculated page C | SD=13% |

Calculations

Acetic acid Production

Energy input

All energy is assumed to come from the heat of combustion in the formation of CO, which is recoverable.

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| Coal | MJ/kg ethylene | 0 | | 3 | kg/kg ethylene | 0 | |
| Oil | MJ/kg ethylene | 0 | 15 | 3 | kg/kg ethylene | 0 | 0.33622909 |
| Natural Gas | MJ/kg ethylene | 0 | | 3 | kg/kg ethylene | 0 | |
| Hydropower | MJ/kg ethylene | 0 | | 3 | | | |

| | | | | | |
|---|---|---|---|---|---|
| | Fission | MJ/kg ethylene | 0 | | 3 |

Material input

Source: Faith Keyes and Clarke's Industrial Chemicals
By F. A. Lowenheim, M. K. Moran
Wiley Interscience, 1975

Methanol Carbonylation method

| Stoichiometric ratios: | | | | |
|---|---|---|---|---|
| Methanol net | Kg/Kg Acetic a | 0.533 | | |
| CO net | Kg/Kg Acetic a | 0.467 | | |
| Methanol input | Kg/Kg Acetic a | 0.5367573 | 0.993 | 0.993 conversion of methanol |
| CO input | Kg/Kg Acetic a | 0.51318681 | 0.91 | 0.91 conversion of CO |
| Producer-Gas input | Kg/Kg Acetic a | 1.69497376 | | from Faith Keyes and Clark's Industrial chemicals, 1975 |
| Coal input | Kg/Kg Acetic a | 0.47330006 | | |

| Emission calculation | (Data from pg D and from AP42 Ed 4 Tbl 1.1-1) | | | |
|---|---|---|---|---|
| Air | | | | |
| CO released from process | Kg/Kg Acetic a | 0.04618681 | 0.09 | unconverted CO |
| Methane | Kg/Kg Acetic a | 0.03050953 | | |
| CO2 | Kg/Kg Acetic a | 0.11356324 | | |
| Particulates | Kg/Kg Acetic a | 0.0085 | 8.5 | g/kg in Cyclone trap outlet (AP42 Ed 4 tbl 1.1-1) |
| Methanol | Kg/Kg Acetic a | 0.0037573 | 0.007 | unconverted assumed to escape in vent stream |
| SOx | Kg/Kg Acetic a | 0.01865878 | 19.5*%S in Co | from AP 42 Ed 4 (1985) tbl 1.1-1 |
| | | | | Coal assumed to have 1% Sulfur and the coal tar product to have 0.4% sulfur |
| Land | | | | |
| Ash | Kg/Kg Acetic a | 0.03599021 | 0.094 | Ash in coal (assumed recovered) but for air emission |

CO production from Coal through synthesis gas (producer or manufactured)

Source: Page D calculations

Producer gas from Coal (Baddelsey)
25.30% mol CO    30.28% wt CO

| | |
|---|---|
| Mw CO | 28.016 |
| Mw Produc | 23.410686 |

Gas product yield from coal: 3.58118218 lb gas/lb coal

Co-Products:

source: calculated from data on this sheet and on sheet D
Coal tar heating value is median for data of Perry Ed 6 (1984) tbl. 9-12

| | | |
|---|---|---|
| Coal Tar | Kg/Kg Acetic a | 0.10515212 |

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| Oil | | | | | Kg/Kg Acetic acid | | |
| Natural Gas | | | | | Kg/Kg Acetic acid | | |
| Coal | Kg/Kg Acetic a | 0.47330006 | | 3 | Kg/Kg Acetic acid | 0.47330006 | |
| Iron ore | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |
| Methanol | Kg/Kg Acetic a | 0.5367573 | | 3 | Kg/Kg Acetic acid | 0.5367573 | |
| Bauxite | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |
| Rock salt | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |
| Clay | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |

Output

Air

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| TSP | Kg/Kg Acetic a | 0.0085 | | | Kg/Kg Acetic acid | 0.0085 | |
| SOx | Kg/Kg Acetic a | 0.01865878 | | | Kg/Kg Acetic acid | 0.01865878 | |
| NOx | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |
| CO | Kg/Kg Acetic a | 0.04618681 | | | Kg/Kg Acetic acid | 0.04618681 | |
| CO2 | Kg/Kg Acetic a | 0.11356324 | | | Kg/Kg Acetic acid | 0.11356324 | |
| H2S | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |
| HCl | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |
| total HC's | Kg/Kg Acetic a | 0.03426683 | | | Kg/Kg Acetic acid | 0.03426683 | |
| other organic | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |
| Heavy metals | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |

Water

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| COD | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |
| BOD | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |
| Acid as H+ | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |
| Metal ions | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |
| Cl2 | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |
| Dissolved Organics | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| suspended solids | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |
| crude oil | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |
| miscelanious dissolved mate | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |
| Phenol | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0 | |

Solid waste

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| Production waste (not innert | Kg/Kg Acetic a | 0.03599021 | | | Kg/Kg Acetic acid | 0.00128 | |
| Toxic chemicals | Kg/Kg Acetic a | 0 | | | Kg/Kg Acetic acid | 0.000001 | |

Sheet Title: MEK (from sec-butanol which is from n-butene which is a byproduct of butadiene production from ethylene. MEK is used in production of TNAZ)

Sheet Description:
Emissions are from TRI database.
Engineering calculation of the Energy requirements and precursor requirements .
This page calculates the vendor emissions from a plant producing $PCl_3$.
Not included are raw material production or extraction or water use.

References/Citations:

Faith Keyes and Clarke's Industrial Chemicals
By F. A. Lowenheim, M. K. Moran
Wiley Interscience, 1975

Perry's Chemical Engineers' Handbook, 6th ed.
McGraw Hill, 1984

AP 42 Ed 4 (1985)
US EPA

SRI Directory of Chemical Producers, US
1993, 1991 editions
SRI International, Menlo Park, CA

US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993
US International Trade Commission, 11.1994

CRC Handbook of Chemistry and Physics, 66th Edition

Summary Output

Co-product Allocation Calculations

Source: US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993
US International Trade Commission, 11.1994

| Mwt | Co-product | Quantity | Units | Quantity | Units |
|---|---|---|---|---|---|
| 137.329 | $PCl_3$ | 1.00E+00 | kg | 1.00E+00 | kg |
| | Total | 1.00E+00 | Kg | 1.00E+00 | Kg |

Notes:

| LCI components | | Unallocated Units | Quantity | Std. Dev. | Allocated Units | Quantity | Std. Dev. | DQI |
|---|---|---|---|---|---|---|---|---|
| **Air** | | | | | | | | |
| | $Cl_2$ | Kg/kg MEK | 4.18147E-06 | | Kg/kg MEK | 4.18147E-06 | | 3 |
| | Zinc oxides/Phos | Kg/kg MEK | 1.136721242 | | Kg/kg MEK | 1.136721242 | | 3 |
| **Water** | | | | | | | | |
| | Dissolved Organ | Kg/kg MEK | 1.73292E-05 | | Kg/kg MEK | 1.73292E-05 | | 3 |
| Solid Wastes | | | | | | | | |
| in container | P4 production w | Kg/kg MEK | 5.85013E-07 | | Kg/kg MEK | 5.85013E-07 | | |
| | Zinc Compounds | Kg/kg MEK | 3.80251E-05 | | Kg/kg MEK | 3.80251E-05 | | |

Resource Consumption

| | | | | |
|---|---|---|---|---|
| Chlorine | Kg/kg MEK | 1.73292E-05 | Kg/kg MEK | 1.73292E-05 |

Notes: This section is where the project specfic calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors

| Unit from | Unit to | Multiplier | Reference | |
|---|---|---|---|---|
| BTU | J | 1055.056 | CRC, 66th Edition | |
| Wh | J | 3600 | CRC, 66th Edition | |
| bbl CrO | BTU CrO | 5800000 | Chemical Engineers' Handbook, 6th ed. | |
| bbl | gal | 42 | Chemical Engineers' Handbook, 6th ed. | |
| gal diesel | BTU diesel | 118500 | Chemical Engineers' Handbook, 6th ed., Figure 9-4 @ S.G. = .76 and sulfur = 0.5% | |
| gal | L | 3.785412 | CRC, 66th Edition | |
| kg | lb | 2.2046226 | CRC, 66th Edition | |
| yr | day | 365 | | |
| m^3 | bbl (petroleum) | 6.289811 | CRC, 66th Edition | |
| gal CrO | lb CrO | 7.2 | | |
| ton | lb | 2000 | | |
| gal fuel oil | BTU fuel oil | 138000 | | |
| cu. ft NG | BTU NG | 1032 | Chemical Engineers' Handbook, 6th ed. | |
| lb Coal (dry | BTU Coal | 12000 | calculation page B | SD=11% |
| kg NG | MJ NG | 46 | Calculated page C | SD=13% |

| | |
|---|---|
| Mw Benzen | 78.1134 |
| Mw Chlorin | 70.9 |
| Mw ClBz | 112.56 |
| Mw Cl2Bz | 147.01 |
| Mw HCl | 36.4609 |
| Mw NaOH | 39.9971 |

| molar dry air composition | | Mwt | mass composition | kg air per kg component |
|---|---|---|---|---|
| N2 | 0.78084 | 28.0134 | 0.75521 | 1.324134 |
| O2 | 0.20946 | 31.9988 | 0.231406 | 4.321406 |
| CO2 | 0.00033 | 44.01 | 0.000501 | 1994.319 |
| Ar | 0.00934 | 39.948 | 0.012882 | 77.62792 |
| total | 0.99997 | 28.96409 | 1 | |

Ideal gas density at 15 C (60 F) — air (dry)

0.042296 mol/liter — 42.29634021 mol/m^3 — 1.225075005 kg/m^3

Calculations

**MEK Production** 1993

Source: US Chemical Industry Statistical Handbook 1994
Chemical Manufacturers Association, Washington DC

| | | | |
|---|---|---|---|
| m ton | 244500 | Mlb | 539.0247 |

**MEK production capacity**

Source: SRI 1991 Directory of Chemical Producers, US

| | | |
|---|---|---|
| | Mlb | 540 |
| Utilization ratio: | Full | 0.998193889 |
| Shell Corporation production at Norco, LA 70079 | Mlb | 230 |
| Calculated production: | | 229.5845944 |

Source: Emissions:
TRI database, 1993 data

The Norco Plant of Shell produces ethylene and propylene and some butylene from mixed LPG (ethane and propane) feedstocks and then manufactures derivatives of butenes into MEK
Production data includes captive production and therefore all relevant emissions may be attributed to that quantity.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| The following reported emissions were deemed unrelated to MEK producti | Allyl Cl | diethanolamine | 1,3 dichloropropylene | | 4 4' iso propyledene diphe | epichlorhydchlorobenz HCl | Cl2 | 1,2 dichloropropane |
| The following reported emissions were ascribed to MEK production only: | MEK | Methyl iso butyl ke | sec-butyl alcohol | Acetone | | | | |
| Emissions allocated between the products (cracker by products) | styrene | toluene | propylene | xylene | ammonia | sulfuric acid titanium tetrachloride | naphthalene | |

Energy and materail input data from the calculations of sheet "Calc"

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| Fossil fuel (general) | MJ/kg PCl3 | 0 | | | MJ/kg PCl3 | 0 | |
| Coal | MJ/kg PCl3 | 0 | | | Kg/kg MEK | 0 | |
| Oil | MJ/kg PCl3 | 0 | 15 | | Kg/kg MEK | 0 | |
| Natural Gas | MJ/kg PCl3 | 0 | | | Kg/kg MEK | 0 | |
| Hydropower | MJ/kg PCl3 | 0 | | | | | |
| Fission | MJ/kg PCl3 | 0 | | | | | |
| Electricity (generic) | MJ/kg PCl3 | 2.88758E-07 | | | MJ/kg P4 | 2.88758E-07 | |
| | | | | | | Probably different mix in US | |

Material input

Co-Products:
source: See from above

Resources:

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. | |
|---|---|---|---|---|---|---|---|---|
| Oil | Kg/kg MEK | 0 | | 4 | Kg/kg MEK | 0 | | |
| Natural Gas | Kg/kg MEK | 0 | | 4 | Kg/kg MEK | 0 | | |
| Coal | Kg/kg MEK | 0 | | 4 | Kg/kg MEK | 0 | | |
| Naphtha | lb/Shell, Norco | 431616341 | | 4 | Kg/kg MEK | 1.879988255 | | |
| ammonia | Kg/kg MEK | 1.73292E-05 | | 4 | Kg/kg MEK | 1.73292E-05 | | (all out into water emission) |
| Silicate (sand) | Kg/kg MEK | 0 | | 4 | Kg/kg MEK | 0 | | |
| Air | Kg/kg MEK | 0 | | 4 | Kg/kg MEK | 0 | | |
| Water | Kg/kg MEK | 0 | | 4 | Kg/kg MEK | 0 | | |

Air

| | LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|---|
| styrene | TSP | Kg/kg MEK | 0 | | | Kg/kg MEK | 0 | |
| | SOx | lb/Shell, Norco | 0 | | | Kg/kg MEK | 0 | |
| | NOx | lb/Shell, Norco | 0 | | | Kg/kg MEK | 0 | |
| | Cl2 | lb/Shell, Norco | 960 | | | Kg/kg MEK | 4.18147E-06 | |
| | CO2 | Kg/kg MEK | 0 | | 3 | Kg/kg MEK | 0 | |
| | P4 | lb/Shell, Norco | 0 | | | Kg/kg MEK | 0 | |
| | Styrene | lb/Shell, Norco | 1.136721242 | | | Kg/kg MEK | 4.95121E-09 | |
| | toluene | lb/Shell, Norco | 878.375505 | | | Kg/kg MEK | 3.82593E-06 | |
| | propylene | lb/Shell, Norco | 2898.639166 | | | Kg/kg MEK | 1.26256E-05 | |
| | xylene | lb/Shell, Norco | 129.9479056 | | | Kg/kg MEK | 5.66013E-07 | |
| | ammonia | lb/Shell, Norco | 7.233680629 | | | Kg/kg MEK | 3.15077E-08 | |
| | sulfuric acid | lb/Shell, Norco | 126.8994259 | | | Kg/kg MEK | 5.52735E-07 | |
| | titanium tetrachloride | lb/Shell, Norco | 191.2791835 | | | Kg/kg MEK | 8.33153E-07 | |
| | naphthalene | lb/Shell, Norco | 82.67063576 | | | Kg/kg MEK | 3.60088E-07 | |
| | MEK | lb/Shell, Norco | 68000 | | | Kg/kg MEK | 0.000296187 | |
| | Methyl iso butyl ketone | lb/Shell, Norco | 15 | | | Kg/kg MEK | 6.53354E-08 | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | sec-butyl alcohol | lb/Shell, Norco | 81000 | | | Kg/kg MEK | 0.000352811 | |
| | Acetone | lb/Shell, Norco | 850 | | | Kg/kg MEK | 3.70234E-06 | |
| | HC total | lb/Shell, Norco | 154181.1822 | | | Kg/kg MEK | 0.000671566 | |
| | Heavy meta(Cd+Ni+Cr) | lb/Shell, Norco | 0 | | | Kg/kg MEK | 0 | |

**Water**

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| COD | lb/Shell, Norco | 0 | | 5 | Kg/kg MEK | 0 | |
| BOD | lb/Shell, Norco | 0 | | 5 | Kg/kg MEK | 0 | |
| Acid, H+ (Phosphoric) | lb/Shell, Norco | 0 | | 5 | Kg/kg MEK | 0 | |
| Metal ions | lb/Shell, Norco | 0 | | 5 | Kg/kg MEK | 0 | |
| Cl2 | lb/Shell, Norco | 0 | | 5 | Kg/kg MEK | 0 | |
| Ammonia | lb/Shell, Norco | 3978.524346 | | 5 | Kg/kg MEK | 1.73292E-05 | |
| suspended solids | lb/Shell, Norco | 0 | | 5 | Kg/kg MEK | 0 | |
| crude oil | lb/Shell, Norco | 0 | | 5 | Kg/kg MEK | 0 | |
| miscelanious dissolved mate | lb/Shell, Norco | 0 | | 5 | Kg/kg MEK | 0 | |
| Phenol | lb/Shell, Norco | 0 | | 5 | Kg/kg MEK | 0 | |

**Solid waste**

| | LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|---|
| | Production waste (not innert) | lb/Shell, Norco | 134.3100149 | | 5 | Kg/kg MEK | 5.85013E-07 | |
| Shipped out | total no catalyst | lb/Shell, Norco | 8729.971082 | | 5 | Kg/kg MEK | 3.80251E-05 | |
| | styrene | lb/Shell, Norco | 8.78375505 | | 6 | Kg/kg MEK | 3.82593E-08 | |
| | toluene | lb/Shell, Norco | 51.66914735 | | 7 | Kg/kg MEK | 2.25055E-07 | |
| | xylene | lb/Shell, Norco | 5.683606209 | | 8 | Kg/kg MEK | 2.4756E-08 | |
| | sulfuric acid | lb/Shell, Norco | 25.83457368 | | 9 | Kg/kg MEK | 1.12527E-07 | |
| | *titanium tetrachloride* | *lb/Shell, Norco* | *14054.00808* | | *10* | *Kg/kg MEK* | *6.12149E-05* | |
| | MEK | lb/Shell, Norco | 3000 | | 11 | Kg/kg MEK | 1.30671E-05 | |
| | Methyl iso butyl ketone | lb/Shell, Norco | 30 | | 12 | Kg/kg MEK | 1.30671E-07 | |
| | Acetone | lb/Shell, Norco | 5608 | | 13 | Kg/kg MEK | 2.44267E-05 | |
| | Heavy metals (Cadmium, Ni | lb/Shell, Norco | 0 | | 5 | Kg/kg MEK | 0 | |
| Sheet End | ======== | ============ | =========== | =========== | =========== | =========== | ============ | ============ |

Values are in capacity Mlb/yr 1993

Source: SRI Directory of Chemical Producers, US
1993, edition
SRI International, Menlo Park, CA

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1400 | 0.297682 | Propylene | | | | | | | | | | |
| | C3H6 | | | | | | | | | | | |
| | 42.081 | | | | | | | | | | | |
| | | | | | **E/P ratio** | | | | | | | |
| 2560 | 0.544333 | **ethylene** | cracked with steam | | **1.8285714** | | | 26.31 | 2.5925926 | **1.937888** | | |
| | C2H4 | | (hydrocracking) | | | | | Ethane | Propane | **Naphtha** | | |
| | 28.054 | | | | | | | | | | | |
| | | | | E | 31.2 | 2560 | | | | | | |
| 500 | 0.106315 | Butadiene | | P | 16.1 | 1400 | | | | | | |
| | C4H6 | | | BD | 4.5 | 500 | | | | | | |
| | 54.092 | | | B | 4.5 | 243 | | | | | | |
| | | | | | 56.3 | 4703 | | 8353.5 | 431.61634 | | | |
| 243 | 0.051669 | **n Butene** | partial oxida | 270 | 0.841099 | **sec butanol** | dehydrogenation over catalyst | 230 | 0.8757179 | **MEK** | 0.038058 | of ethylene emissions |
| | C4H8 | | | | | C4H10O | | | | C4H8O | | |
| | 56.108 | | | | | 74.12 | | | | 72.1 | | |
| | | | | | | | | | | | 0.875718 | of sec butanol emissions |
| 4703 | | | | | | | | | | | | |

| **100% weighted** | Air | Water | land | waste shipped out |
|---|---|---|---|---|
| MEK | 68000 | | 130 | 3000 |
| Methyl iso butyl ketone | 15 | | | 30 |
| sec-butyl alcohol | 81000 | | 4 | |
| Acetone | 850 | | | 5608 |
| **Cracker weighted** | 0.0516691 | | | |

| | Air | Water | land | waste shipped out | Air | Water | land | waste shipped out |
|---|---|---|---|---|---|---|---|---|
| styrene | 22 | | | 170 | 1.136721 | | | 8.783755 |
| toluene | 17000 | | | 1000 | 878.3755 | | | 51.66915 |
| propylene | 56100 | | | | 2898.639 | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| xylene | 2515 | | | 110 | | 129.9479 | | | 5.683606 |
| ammonia | 140 | 77000 | | | | 7.233681 | 3978.5 | | |
| sulfuric acid | 2456 | | 6 | 500 | | 126.8994 | | 0.3100149 | 25.83457 |
| titanium tetrachloride | 3702 | | | 272000 | reclamation | 191.2792 | | | 14054.01 |
| naphthalene | 1600 | | | | | 82.67064 | | | |

Sheet Title: butylene (for butadiene and rubber production)

Sheet Description: This page calculates the vendor-independent emissions from european refineries producing monomer quality butylene
Included are oil extraction and transportation from the well head to the refinery.

References/Citations: SimaPro3 (entry of Nov 18 94)
Average data for 19 european cracking fascilities producing monomer quality ethylene.
taken from:
PWMI/APME, Ecoprofiles of the European plastics industry, 1992-1994
report 2, tbl 36 pg 21

Summary Output

Co-product Allocation Calculations

| Co-product | Quantity | Units |
|---|---|---|
| butylene | 1.00E+00 | Kg |
| Total | 1 | Kg |

| LCI components | Unallocated Units | Quantity | Std. Dev. | Allocated Units | Quantity | Std. Dev. | DQI |
|---|---|---|---|---|---|---|---|
| Air | | | | | | | |
| TSP | Kg/Kg butylene | 0.0008 | | | | | 3 |
| SOx | Kg/Kg butylene | 0.004 | | | | | 3 |
| NOx | Kg/Kg butylene | 0.006 | | | | | 3 |
| CO | Kg/Kg butylene | 0.0004 | | | | | 3 |
| CO2 | Kg/Kg butylene | 0.5 | | | | | 3 |
| H2S | Kg/Kg butylene | 0.000001 | | | | | 3 |
| HCl | Kg/Kg butylene | 0.00001 | | | | | 3 |
| total HC's | Kg/Kg butylene | 0.007 | | | | | 3 |
| other organic | Kg/Kg butylene | 0.000001 | | | | | 3 |
| Heavy metals | Kg/Kg butylene | 0.000001 | | | | | 3 |
| Water | | | | | | | |
| COD | Kg/Kg butylene | 0.0002 | | | | | 3 |
| BOD | Kg/Kg butylene | 0.00004 | | | | | 3 |
| Acid as H+ | Kg/Kg butylene | 0.00004 | | | | | 3 |
| Metal ions | Kg/Kg butylene | 0.0003 | | | | | 3 |
| Cl2 | Kg/Kg butylene | 0.00005 | | | | | 3 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Dissolved Organ | Kg/Kg butylene | 0.00002 | | | 3 |
| | suspended solid | Kg/Kg butylene | 0.0002 | | | 3 |
| | crude oil | Kg/Kg butylene | 0.0001 | | | 3 |
| | miscelanious dis | Kg/Kg butylene | 0.0004 | | | 3 |
| | total HC's | Kg/Kg butylene | 0.00009 | | | |
| | Phenol | Kg/Kg butylene | 0.000001 | | | 3 |
| | Solid Wastes | | | | | |
| | Production waste | Kg/Kg butylene | 0.0083 | | | 3 |
| Resource Consumption | | | | | | |
| | Natural Gas | Kg/Kg butylene | 0.533478261 | 20450000 | | 3 |
| fuel | Natural Gas | Kg/Kg butylene | 0.143913043 | 5516666.667 | #VALUE! | |
| | Crude Oil | Kg/Kg butylene | 0.789017599 | 140.3907175 | #VALUE! | |
| fuel | Crude Oil | Kg/Kg butylene | 0.036088589 | 6.421279978 | #VALUE! | |
| | Coal | Kg/Kg butylene | 0.000358269 | | | |
| fuel | Coal | Kg/Kg butylene | 0.017196902 | 3.059862621 | | 3 |
| | Hydropower | MJ/Kg butylene | 0.06 | | | |
| | Fission | MJ/Kg butylene | 0.22 | | | |
| | Iron ore | Kg/Kg butylene | 0.0002 | | | |
| | limestone | Kg/Kg butylene | 0.0001 | | | |
| | Bauxite | Kg/Kg butylene | 0.0003 | | | |
| | Rock salt | Kg/Kg butylene | 0.006 | | | |
| | Clay | Kg/Kg butylene | 0.00002 | | | |
| | Water | Kg/Kg butylene | 1.6 | | | |

Notes: This section is where the project specfic calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors

| Unit from | Unit to | Multiplier | Reference |
|---|---|---|---|
| BTU | J | 1055.056 | CRC, 66th Edition |
| Wh | J | 3600 | CRC, 66th Edition |
| bbl CrO | BTU CrO | 5800000 | Chemical Engineers' Handbook, 6th ed. |
| bbl | gal | 42 | Chemical Engineers' Handbook, 6th ed. |
| gal diesel | BTU diesel | 118500 | Chemical Engineers' Handbook, 6th ed., Figure 9-4 @ S.G. = .76 and sulfur = 0.5% |
| gal | L | 3.785412 | CRC, 66th Edition |
| kg | lb | 2.2046226 | CRC, 66th Edition |
| yr | day | 365 | |
| m^3 | bbl (petroleum) | 6.289811 | CRC, 66th Edition |
| gal CrO | lb CrO | 7.2 | |

| | | | | |
|---|---|---|---|---|
| ton | lb | 2000 | | |
| gal fuel oil | BTU fuel oil | 138000 | | |
| cu. ft NG | BTU NG | 1032 | Chemical Engineers' Handbook, 6th ed. | |
| lb Coal (dry) | BTU Coal | 12000 | calculation page B | SD=11% |
| kg NG | MJ NG | 46 | Calculated page C | SD=13% |

Calculations

Ethylene Production

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|---|
| butylene (polymer) | 1 Kg | | | | 3 | | | |
| butylene (other) | | | | | | | | |
| | | | | | | | 0 | |

SimaPro3
Average data for 19 european cracking fascilities producing monomer quality butylene.
taken from:
PWMI/APME, Ecoprofiles of the European plastics industry, 1992-1994
report 2, tbl 36 pg 21

Energy input

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|---|
| Coal | MJ/Kg butylene | 0.48 | | | 3 | Kg/Kg butylene | 0.017196902 | |
| Oil | MJ/Kg butylene | 1.61 | | | 3 | Kg/Kg butylene | 0.036088589 | |
| Natural Gas | MJ/Kg butylene | 6.62 | | | 3 | Kg/Kg butylene | 0.143913043 | |
| Hydropower | MJ/Kg butylene | 0.06 | | | 3 | MJ/Kg butylene | 0.06 | |
| Fission | MJ/Kg butylene | 0.22 | | | 3 | MJ/Kg butylene | 0.22 | |
| | | | | | | | Probably different mix in US | |

Material input

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|---|
| Oil | MJ/Kg butylene | 35.2 | | | 3 | Kg/Kg butylene | 0.789017599 | |
| Natural Gas | MJ/Kg butylene | 24.54 | | | 3 | Kg/Kg butylene | 0.533478261 | |
| Coal | MJ/Kg butylene | 0.01 | | | 3 | Kg/Kg butylene | 0.000358269 | |
| Iron ore | Kg/Kg butylene | 0.0002 | | | 3 | Kg/Kg butylene | 0.0002 | |
| limestone | Kg/Kg butylene | 0.0001 | | | 3 | Kg/Kg butylene | 0.0001 | |
| Bauxite | Kg/Kg butylene | 0.0003 | | | 3 | Kg/Kg butylene | 0.0003 | |
| Rock salt | Kg/Kg butylene | 0.006 | | | 3 | Kg/Kg butylene | 0.006 | |
| Clay | Kg/Kg butylene | 0.00002 | | | 3 | Kg/Kg butylene | 0.00002 | |
| Water | Kg/Kg butylene | 1.6 | | | 3 | Kg/Kg butylene | 1.6 | |

Output
Air

| | Raw/ | Raw/ | Raw/ | | | Transformed | Transformed | Transformed |
|---|---|---|---|---|---|---|---|---|

| LCI component | Input Units | Input Quan. | Input Std. Dev. | DQI | Units | Quan. | Std. Dev. |
|---|---|---|---|---|---|---|---|
| TSP | Kg/Kg butylene | 0.0008 | | | Kg/Kg butylene | 0.0008 | |
| SOx | Kg/Kg butylene | 0.004 | | | Kg/Kg butylene | 0.004 | |
| NOx | Kg/Kg butylene | 0.006 | | | Kg/Kg butylene | 0.006 | |
| CO | Kg/Kg butylene | 0.0004 | | | Kg/Kg butylene | 0.0004 | |
| CO2 | Kg/Kg butylene | 0.5 | | | Kg/Kg butylene | 0.5 | |
| H2S | Kg/Kg butylene | 0.000001 | | | Kg/Kg butylene | 0.000001 | |
| HCl | Kg/Kg butylene | 0.00001 | | | Kg/Kg butylene | 0.00001 | |
| total HC's | Kg/Kg butylene | 0.007 | | | Kg/Kg butylene | 0.007 | |
| other organic | Kg/Kg butylene | 0.000001 | | | Kg/Kg butylene | 0.000001 | |
| Heavy metals | Kg/Kg butylene | 0.000001 | | | Kg/Kg butylene | 0.000001 | |

Water

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| COD | Kg/Kg butylene | 0.0002 | | | Kg/Kg butylene | 0.0002 | |
| BOD | Kg/Kg butylene | 0.00004 | | | Kg/Kg butylene | 0.00004 | |
| Acid as H+ | Kg/Kg butylene | 0.00004 | | | Kg/Kg butylene | 0.00004 | |
| Metal ions | Kg/Kg butylene | 0.0003 | | | Kg/Kg butylene | 0.0003 | |
| Cl2 | Kg/Kg butylene | 0.00005 | | | Kg/Kg butylene | 0.00005 | |
| Dissolved Organics | Kg/Kg butylene | 0.00002 | | | Kg/Kg butylene | 0.00002 | |
| suspended solids | Kg/Kg butylene | 0.0002 | | | Kg/Kg butylene | 0.0002 | |
| crude oil | Kg/Kg butylene | 0.0001 | | | Kg/Kg butylene | 0.0001 | |
| miscelanious dissolved mater | Kg/Kg butylene | 0.0004 | | | Kg/Kg butylene | 0.0004 | |
| HC's | Kg/Kg butylene | 0.00009 | | | Kg/Kg butylene | 0.00009 | |
| Phenol | Kg/Kg butylene | 0.000001 | | | Kg/Kg butylene | 0.000001 | |

Solid waste

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Production waste (not innert) | Kg/Kg butylene | 0.0083 | | | Kg/Kg butylene | 0.0083 | |

Sheet End ========= ============ ============ ============ ============ ============ ============== ============ ============ ========= ========= =========

| Coal type | Moisture % | Sulfur % | %dry | Heat value Btu/lb | Btu/lbdry | | | |
|---|---|---|---|---|---|---|---|---|
| Sub bit C | 26 | 0.3 | 0.41 | 8230 | 11121.622 | | | |
| HV bit A | 2.9 | 0.6 | 0.62 | 14170 | 14593.203 | low sulfur coal heating value | | |
| Sub bit B | 22.2 | 0.5 | 0.64 | 9610 | 12352.185 | | | |
| Brown Coal German - Rh | 55 | 0.3 | 0.67 | 4830 | 10733.333 | | | |
| Sub bit A | 13.9 | 0.6 | 0.70 | 10330 | 11997.677 | SD= | 1295.7751 | 0.1081691 |
| Meta Anthracite | 9 | 0.7 | 0.77 | 10080 | 11076.923 | Avg= | 11979.157 | |
| LV bit | 2.9 | 0.8 | 0.82 | 14400 | 14830.072 | median | | |
| Anthracite | 4.3 | 0.8 | 0.84 | 12880 | 13458.725 | | | |
| Lignite | 36.8 | 0.9 | 1.42 | 7000 | 11075.949 | | | |
| MV bit | 2.4 | 1.5 | 1.54 | 14490 | 14846.311 | | | |
| Semi anthracite | 2.1 | 1.7 | 1.74 | 13700 | 13993.871 | | | |
| HV bit B | 6.7 | 2.6 | 2.79 | 12390 | 13279.743 | | | |
| HV bit C | 15.4 | 2.9 | 3.43 | 10740 | 12695.035 | | | |

bit=Bituminous
V=Volatility
L=low
M=Medium
H=high

Source: Kirk Othmer vol 4 1949

Natural gas

| mol% | Mwt | heat value MJ/M^3 | Rio Arriba, N | Terrell, Tex | Stanton, Kan | San Juan, NM | Olds Field, A | Cliffside, Texas | avg | SD (rel) |
|---|---|---|---|---|---|---|---|---|---|---|
| Methane | 16.043 | 37.57 | 96.91 | 45.64 | 67.56 | 77.28 | 52.34 | 65.8 | | |
| ethane | 30.07 | 65.83 | 1.33 | 0.21 | 6.23 | 11.18 | 0.41 | 3.8 | | |
| propane | 44.097 | 93.6 | 0.19 | | 3.18 | 5.83 | 0.14 | 1.7 | | |
| butane | 58.123 | 120.98 | 0.05 | | 1.42 | 2.34 | 0.16 | 0.8 | | |
| pentane+ | 72.15 | 148.84 | 0.02 | | 0.04 | 1.18 | 0.41 | 0.5 | | |
| $CO_2$ | 44.01 | 0 | 0.82 | 53.93 | 0.07 | 0.8 | 8.22 | | | |
| $H_2S$ | 34.076 | 23.7 | | 0.01 | | | 35.79 | | | |
| $N_2$ | 28.013 | 0 | 0.68 | 0.21 | 21.14 | 1.39 | 2.53 | 25.6 | | |
| Mol wt: | | | 16.625849 | 31.182 | 20.921258 | 21.28362 | 25.492892 | 20.445665 | 19.610242 | 10.79% |
| heating value | MJ/M^3 | | 37.6 | 17.3 | 34.9 | 46.8 | 30 | 30.7 | 39.766667 | 12.81% |
| | MJ/KG | | 50.658467 | 12.427683 | 37.366777 | 49.254778 | 26.360289 | 33.634514 | 45.760008 | 13.03% |
| | 0.0224M^3/mol | | | too high $CO_2$ content for use | | | too high Sulfur content | too low heating value(?) | | |

Source: Kirk Othmer Ed 4 vol 12 1993

MJ/m^3

Heating values for processed city natural gas:
source Perry 6 (1964)
averaged from table 9-14

Btu/scf 1049.5714

Synopsis of table 9-14

| mol% | Mwt | heat value MJ/M^3 | Baltimore Md | Columbus Ohio | Houston Tx | Burmingham Al | Washington DC | Phoenix Az |
|---|---|---|---|---|---|---|---|---|
| Methane | 16.043 | 37.57 | 94.4 | 93.14 | 92.5 | 93.14 | 95.15 | 87.37 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| ethane | 30.07 | 65.83 | 3.4 | 3.58 | 4.8 | 2.5 | 2.84 | 8.11 | | |
| propane | 44.097 | 93.6 | 0.6 | 0.66 | 2 | 0.67 | 0.63 | 2.26 | | |
| butane | 58.123 | 120.98 | 0.5 | 0.22 | 0.3 | 0.32 | 0.24 | 0.13 | | |
| pentane+ | 72.15 | 148.84 | 0 | 0.09 | 0 | 0.12 | 0.05 | 0 | | |
| CO2 | 44.01 | 0 | 0.6 | 0.85 | 0.27 | 1.06 | 0.62 | 0.61 | | |
| H2S | 34.076 | 23.7 | | 0.01 | | | | | | |
| N2 | 28.013 | 0 | 0.5 | 0.21 | 21.14 | 2.14 | 0.42 | 1.37 | avg | SD (rel) |
| Mol wt: | | | 17.126294 | 16.939122 | 23.380219 | 17.328208 | 16.9628 | 18.179837 | 18.319413 | 15.84% |
| heating value | MJ/M^3 | | 39.2023 | 38.3444 | 38.4563 | 38.1952 | 38.8666 | 39.9483 | 38.835517 | 1.10% |
| | MJ/KG | | 51.273879 | 50.705967 | 36.844014 | 49.374551 | 51.324771 | 49.221668 | 48.124142 | 13.30% |

0.0224M^3/mol

Sheet Title: MTBE (from Methanol and Isobutelene. MTBE is used in production of TNAZ)

Sheet Description:
Emissions are from TRI database.
Engineering calculation of the Energy requirements.
Precursor material requirements are from EIA.
This page calculates the vendor emissions from a plant producing MTBE.
Not included are raw material production or extraction or water use.

References/Citations:

Faith Keyes and Clarke's Industrial Chemicals
By F. A. Lowenheim, M. K. Moran
Wiley Interscience, 1975

Perry's Chemical Engineers' Handbook, 6th ed.
McGraw Hill, 1984

AP 42 Ed 4 (1985)
US EPA

SRI Directory of Chemical Producers, US
1993, 1991 editions
SRI International, Menlo Park, CA

US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993
US International Trade Commission, 11.1994

CRC Handbook of Chemistry and Physics, 66th Edition

Summary Output

Co-product Allocation Calculations

Source: US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993
US International Trade Commission, 11.1994

| Mwt | Co-product | Quantity | Units | Quantity | Units | BP deg C | Sp G | Vapor density relative to air |
|---|---|---|---|---|---|---|---|---|
| 88.1492 | MTBE | 1.00E+00 | kg | 1.00E+00 | kg | 8.2 | 1.392 | 3.4 |
| | Total | 1.00E+00 | Kg | 1.00E+00 | Kg | | | |

Notes:

| LCI components | Unallocated Units | Quantity | Std. Dev. | Allocated Units | Quantity | Std. Dev. | DQI |
|---|---|---|---|---|---|---|---|
| **Air** | | | | | | | |
| MTBE | Kg/kg MTBE | 7.31922E-06 | | Kg/kg MTBE | 7.31922E-06 | | 5 |
| Methanol | Kg/kg MTBE | 2.13838E-05 | | Kg/kg MTBE | 2.13838E-05 | | 5 |
| Ammonia | Kg/kg MTBE | 4.09116E-09 | | Kg/kg MTBE | 4.09116E-09 | | 5 |
| **Water** | | | | | | | |
| MTBE | Kg/kg MTBE | 3.25744E-08 | | Kg/kg MTBE | 3.25744E-08 | | 5 |
| Methanol | Kg/kg MTBE | 5.42907E-06 | | Kg/kg MTBE | 5.42907E-06 | | 5 |
| Ammonia | Kg/kg MTBE | 1.65873E-07 | | Kg/kg MTBE | 1.65873E-07 | | 5 |
| Solid Wastes | | | | | | | |

Resource Consumption

| | | | | | |
|---|---|---|---|---|---|
| Electric Power | MJ/Kg MTBE | 9.94219E-08 | MJ/Kg MTBE | 9.94219E-08 | 3 |
| Isobutylene | Kg/kg MTBE | 0.844445946 | Kg/kg MTBE | 0.844445946 | 5 |
| Methanol | Kg/kg MTBE | 0.273010811 | Kg/kg MTBE | 0.273010811 | 5 |

Notes: This section is where the project specfic calculations take place. Information on LCI components from below is taken and the proper co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the co-product allocation rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest. A value of 0 is used when no indicator was reported.

Conversion Factors

| Unit from | Unit to | Multiplier | Reference | |
|---|---|---|---|---|
| BTU | J | 1055.056 | CRC, 66th Edition | |
| Wh | J | 3600 | CRC, 66th Edition | |
| bbl CrO | BTU CrO | 5800000 | Chemical Engineers' Handbook, 6th ed. | |
| bbl | gal | 42 | Chemical Engineers' Handbook, 6th ed. | |
| gal diesel | BTU diesel | 118500 | Chemical Engineers' Handbook, 6th ed., Figure 9-4 @ S.G. = .76 and sulfur = 0.5% | |
| gal | L | 3.785412 | CRC, 66th Edition | |
| kg | lb | 2.2046226 | CRC, 66th Edition | |
| yr | day | 365 | | |
| p.s.i. | feet water | 2.03666 | CRC, 66th Edition | |
| m^3 | bbl (petroleum) | 6.289811 | CRC, 66th Edition | |
| gal CrO | lb CrO | 7.2 | | |
| ton | lb | 2000 | | |
| gal fuel oil | BTU fuel oil | 138000 | | |
| cu. ft NG | BTU NG | 1032 | Chemical Engineers' Handbook, 6th ed. | |
| lb Coal (dry | BTU Coal | 12000 | calculation page B | SD=11% |
| kg NG | MJ NG | 46 | Calculated page C | SD=13% |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| d MTBE | 0.74 | rel to Water | molar | | | | kg air per kg |
| Mw Chlorin | 70.9 | | dry air composition | | Mwt | mass composition | component |
| Mw ClBz | 112.56 | | N2 | 0.78084 | 28.0134 | 0.75521 | 1.324134 |
| Mw Cl2Bz | 147.01 | | O2 | 0.20946 | 31.9988 | 0.231406 | 4.321406 |
| Mw HCl | 36.4609 | | CO2 | 0.00033 | 44.01 | 0.000501 | 1994.319 |
| Mw NaOH | 39.9971 | | Ar | 0.00934 | 39.948 | 0.012882 | 77.62792 |
| | | | total | 0.99997 | 28.96409 | 1 | |

Ideal gas density at 15 C (60 F) — air (dry)

0.042296 mol/liter 42.29634021 mol/m^3 1.225075005 kg/m^3

**Calculations**

**MTBE Production**

Source: US ITC 2810 11.94 Synthetic Organic Che Kg — 1993: 5547491608 — 5547491608

US Production and Sales, 1993

**MTBE production capacity**

Source: SRI 1993 Directory of Chemical Producers, US

Mlb 15149

Utilization ratio: chemical industry average 199 0.80732229

| | | Capacity Mlb | Calculated production: Mlb |
|---|---|---|---|
| Global Octanes Corporation | Deer Park, Tx | 1150 | 928.4206337 |

Exxon    Baton Rouge, LA 70821    333    268.8383226

Source: Emissions:
TRI database, 1993 data
The Van de Mark plant is the only manufacturer of MTBE for open sale on the market so only its TRI data are used

| The following reported emissions were ascribed to MTBE production only: | | MTBE | Methanol | Isobutylene | Cr | Ammonia | |
|---|---|---|---|---|---|---|---|
| Global Octanes Corporation | Air | 3.00E+00 | 2.00E+00 | | | | 4 |
| | Water | 0.00E+00 | 0.00E+00 | | | | 154 |
| Exxon | Air | 8.76E+03 | 2.56E+04 | | | | |
| | Water | 3.90E+01 | 6.50E+03 | | | | |

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| Fossil fuel (general) | MJ/kg MTBE | 0 | | | MJ/kg MTBE | 0 | |
| Coal | MJ/kg MTBE | 0 | | | Kg/kg MTBE | 0 | |
| Oil | MJ/kg MTBE | 0 | | | Kg/kg MTBE | 0 | |
| Natural Gas | MJ/kg MTBE | 0 | | | Kg/kg MTBE | 0 | |
| Hydropower | MJ/kg MTBE | 0 | | | | | |
| Fission | MJ/kg MTBE | 0 | | | | | |
| Electricity (generic) | MJ/kg MTBE | 9.94219E-08 | | | MJ/kg MTBE | 9.94219E-08 | |

Cooling water

25 deg C temp rise
0 heat removal MJ/kg water
0 MJ/kg product
c water    0 Kg/Kg product    0.7 efficiency

7.87E-05 kJ Elec/Kg    Based on viscosity and density of water for a 250 ft static head per pumping stage in 40hr week & 52 week year daytime operation. multiply by specific gravity of material and relative viscosity to that of water.

| | | representative m | Sp grav | Sp visc | kgflow/kg prod | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| reactor | to wash, to | MTBE | 0.74 | 0.233 | MJ/kg MTBE | 1.35739E-08 | vicosity of EE ether | 200 psi = | 376.7821 | | | | | | |
| storage | to reactor | Methanol to P=20 | 0.791 | 0.597 | MJ/kg MTBE | 7.87077E-08 | | | | | | | | | |
| storage | to reactor | Isobutylene P to | 0.5942 | 0.223 | MJ/kg MTBE | 7.14023E-09 | | | | 2 | 5.5 | 8 | 8 | 1 | 24.5 |
| cooling water | | | 1 | 1 | 0 | 0 | | | | 6 | 2.5 | | | 7 | 15.5 |
| | | CRC 66 | CRC 66 | | | 9.94219E-08 | total pumping energy per kg prod | | | | | | | | |
| | | MTBE from Hawley's | | | | | | | | | | | | | |

Co-Products:    40
source: See from above

Resources: Faith, Keyes and Clark'e Industrial chemicals

| | LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Oil | Kg/kg MTBE | 0 | | | Kg/kg MTBE | 0 | | | |
| | Natural Gas | Kg/kg MTBE | 0 | | | Kg/kg MTBE | 0 | | | |
| | Coal | Kg/kg MTBE | 0 | | | Kg/kg MTBE | 0 | | | |
| 29.0183 | Methanol | Gal/Gal MTBE | 0.79 | | 5 | Kg/kg MTBE | 0.844445946 | | US Petroleum refining | "Meeting Requirements for Cleaner Fuels and Refineries" |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 58.123 | Isobutylene | Gal/Gal MTBE | 0.34 | | | 5 Kg/kg MTBE | 0.273010811 | | National Petroleum Counc Vol1, Aug 1993 | pg148 |
| | Ion exchange resin (acidic) | Kg/kg MTBE | 0 | ? | | Kg/kg MTBE | 0 | | | |
| | Air | Kg/kg MTBE | 0 | | | Kg/kg MTBE | 0 | | | |
| | Water | Kg/kg MTBE | 0 | | | Kg/kg MTBE | 0 | | | |

**Air**

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. | |
|---|---|---|---|---|---|---|---|---|
| TSP | Kg/kg MTBE | 0 | | | Kg/kg MTBE | 0 | | |
| SOx | kg/kg MTBE | 0 | | | Kg/kg MTBE | 0 | | |
| NOx | kg/kg MTBE | 0 | | | Kg/kg MTBE | 0 | | |
| Cl2 | kg/kg MTBE | 0 | | | Kg/kg MTBE | 0 | | |
| CO2 | kg/kg MTBE | 0 | | 3 | Kg/kg MTBE | 0 | | |
| MTBE | kg/kg MTBE | 8.76E+03 | | | Kg/kg MTBE | 7.31922E-06 | | Industrial practice is to leave excess C |
| Methanol | kg/kg MTBE | 2.56E+04 | | | Kg/kg MTBE | 2.13838E-05 | | |
| Ammonia | kg/kg MTBE | 4.90E+00 | | | Kg/kg MTBE | 4.09116E-09 | | |
| HC total | kg/kg MTBE | 0 | | | Kg/kg MTBE | 0 | | |
| Heavy meta(Cd+Ni+Cr) | kg/kg MTBE | 0 | | | Kg/kg MTBE | 0 | | |

**Water**

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. | |
|---|---|---|---|---|---|---|---|---|
| COD | lb/Exxon +Glob | 0 | | 5 | Kg/kg MTBE | 0 | | |
| BOD | lb/Exxon +Glob | 0 | | 5 | Kg/kg MTBE | 0 | | |
| Acid, H+ (Phosphoric) | lb/Exxon +Glob | 0 | | 5 | Kg/kg MTBE | 0 | | |
| Metal ions | lb/Exxon +Glob | 0 | | 5 | Kg/kg MTBE | 0 | | |
| Cl2 | lb/Exxon +Glob | 0 | | 5 | Kg/kg MTBE | 0 | | |
| CO2 | lb/Exxon +Glob | 0 | | 5 | Kg/kg MTBE | 0 | | |
| MTBE | lb/Exxon +Glob | 3.90E+01 | | 5 | Kg/kg MTBE | 3.25744E-08 | | |
| Methanol | lb/Exxon +Glob | 6.50E+03 | | 5 | Kg/kg MTBE | 5.42907E-06 | | |
| Ammonia | lb/Exxon +Glob | 198.5930435 | | 5 | Kg/kg MTBE | 1.65873E-07 | | Exxon plant uses ammonia predominantly for other purposes |
| Heavy metals (Cadmium, Ni | db/Exxon +Glob | 0 | | 5 | Kg/kg MTBE | 0 | | |

**Solid waste**

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| Production waste (not innert) | lb/Exxon +Glob | 0 | | 5 | Kg/kg MTBE | 0 | |
| Heavy metals (Cadmium, Ni | db/Exxon +Glob | 0 | | 5 | Kg/kg MTBE | 0 | |

**Offsite Transfer**

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|
| Chromium (catalyst?) | lb/Exxon +Glob | 541580 | | | Kg/kg MTBE | 0.00045235 | |

Sheet End ======== ============ =========== =========== =========== =========== ============= ============= =========== =================== ======== ========

Sheet Title: Corn Production Last Modified 10/06/95

Sheet Description:

This page includes calculations of the average resource consumption and emissions from the production of corn in the United States. This includes information on the embodied energy in materials used such as fertilizers, pesticides and insecticides, lime, and seed.
It does not include embodied energy to manufacture farm machinery or buildings.
All basic data is converted into units of input or output per bushel (bu) of corn output.

Many of the calculations below are adjusted to account for the relationship of harvested to planted acres. Typically, only about 98-99% of planted corn acres are harvested. Some resources have gone into this planting however, such as seed, fertilizer, energy, etc. For this reason, yields and resource consumption are adjusted to account for unharvested acreage.

Air emissions are also broken out by source in the columns to the right of the allocated emissions. These are expressed both as quantity per bushel, and as a percentage of total emissions. In this way the most important sources of air emissions can be identified, and the veracity of the estimates checked.

Also provided in a table to the right are some other recent estimates of energy use to produce corn, and a discussion of why the results of the studies vary. Fortunately, though estimates of energy use for particular inputs vary considerably, this variation in most cases is cancelled out, that the overall energy intensity values are fairly consistent. It is hoped that the detailed methodology followed below is not only accurate, but resource use data important to the assessment of secondary impacts (e.g. emissons from fertilizer manufacture).

Note: Blanchard estimates that 1-3% of corn is removed in the cleaning process at the mill. Since this corn is used in feed, the corn balance presented in the corn refining material balance accounts for this loss.

References/Citations:


Ali, Mir, and W. McBride. 1994. Corn: State-Level Production Costs, Characteristics, and Input Use, 1991, USDA/ERS, SB-891.

2 Anderson, I.C., and J. S. Levine. 1987. Simultaneous Field Measurements of Biogenic Emissions of Nitric Oxide and Nitrous Oxide, Journal of Geophyical Research, vol. 92, no. D1, pp. 965-976, January, 1987.

3 Austin, George T. 1984. Shreve's Chemical Process Industries, Fifth Edition, McGraw-Hill, New York

4 Battaglin, W.A., D.A. Goolsby, and D.K. Mueller. 1994. Relations Between Use, Concentration, and Transport of Agricultural Chemicals in the Mississippi River Basin, in Proceedings of the Annual Summer Symposium of the American Water Resource Association, Effects of Human Induced Changes on Hydrologic Systems, June 26-29, 1994, Jackson Hole, Wyoming.

5 Bhat, Mahadev G., Burton C. English, Anthony Turhollow, and Herzron Nyangito. 1993. Energy Use in Synthetic Agricultural Inputs: Revisited, Report prepared by the Department of Agricultural Economics and Rural Sociology, The University of Tennessee, Knoxville, for Biofuels Feedstock Development Program Environmental Sciences Division, Oak Ridge National Laboratory, ORNL/Sub/90-99732/2.

6 Blanchard, Paul H. 1992. Technology of Corn Wet Milling and Associated Processes, Industrial Chemical Library, vol. 4, Elsevier Press, New York.

7 Blankenhorn, Paul R., et al. 1986. Net Financial and Energy Analyses for Producing Populus Hybrid Under Four Management Strategies: First Rotation, Oak Ridge Nat'l Laboratory, ORNL/Sub/79-07928/1.

8 Boynton, Robert S. 1980. Chemistry and Technology of Lime and Limestone, Second Edition, John Wiley and Sons, Inc., New York.

9 Bowman, B.T., et al. 1994. Tranport of Herbicides and Nutrients in Surface Runoff from Corn Cropland in Southern Ontario Canadian Journal of Soil Science, 7491):59-66, 1994

10 Buhler, D.D., et al. 1993. Water Quality: Atrazine and Alachlor Losses from Subsurface Tile Drainage of a Clay Loam Soil, Journal of Environmental Quality, 22:583-588, 1993

11 Chambers, R.S., et al. 1979. Gasohol: Does It or Doesn't It Produce Positive Net Energy, Science, vol. 206, November 1979, pp. 789-795.

12 DeLuchi, M. 1993. Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity,


Energy Use in Corn Production

| Item | Study Shapouri et al | Lorenz et al 19 | This Study |
|---|---|---|---|
| Nitrogen | 22,631 | 28,295 | 23,866 |
| Potash | 539 | 2,390 | 956 |
| Phosphate | 1,992 | 2,417 | 1,635 |
| Lime | 1,232 | - | 748 |
| Chemicals | 5,766 | 2,704 | 2,697 |
| All Other | 23,024 | 33,386 | 24,049 |
| Total | 55,184 | 69,192 | 53,952 |

Notes: Both this study and Shapouri rely on the same source of information for on-farm energy us
use is lumped into the category "other" and it can be seen that the two estimates are very close. S
for pesticides from Pimentel (1991) which appears to find its genesis in another Pimentel work (19
to come from Pimentel 1991, but may come from Pimentel 1988, where it is cited at 100 KJ/kg. C
that it includes energy for formulation, packaging, and transport. Shapouri adds energy use for inp
counting. The 1980 estimate for packaging, formulation, and transport is also much higher than co
use at least some fairly crude assumptions about distances and modes hauled. Lacking further in
is consistent with the estimate in Lorenz, and probably derives from the same original data. Energ
quantify precisely. Each form of fertilizer requires different amounts of energy. Both Shapouri and
that were aggregated up from fertilizer type specific data. In this report fertilizer type specific data
the types of fertilizers used with corn to develop a corn specific value. In any case, the estimates
higher than those used by Shapouri and this report, however they include transportation, packagi
The packaging, transportation, and application estimates were derived from a source specifically
fertilizer is sold in bulk, these estimates themselves may be high. Lorenz also uses a very high es
from an estimate that 16% of corn is irrigated. Both this report and the Shapouri report use data fr
use (including irrigation). Since the fraction of corn irrigated in the midwest is very small, this may
intensity estimates.

Argonne National Laboratory, ANL/ESD/TM-22, Vol. 2.

13 Eichner, Melissa. 1990. Nitrous Oxide Emissions from Fertilized Soils: Summary of Available Data, J. of Environmental Quality, 19:272-280(1990)

14 The Fertilizer Institute. 1982. The Fertilizer Handbook

15 Giampietro, M., and David Pimentel. 1990. Alcohol and Biogass Production from Biomass, Critical Reviews in Plant Sciences, Vol. 9, No. 3, pp. 213-233.

16 Glotfelty, D.E., et al. 1984. Atrazine and Simazine Movement to the Wye River Estuary, Journal of Environmental Quality, 13:115-121

17 Goolsby, D.A., E.M. Thurman, M.L. Pomes, and W.A. Battaglin. 199. Temporal and Geographic Distribution of Herbicides in Precipitation in the Midwest and Northeast United States, 1990-1991, in Proceedings of the Fourth National Conference on Pesticides, New Directions in Pesticide Research, Development and Policy, November 1-3, 1993, Blacksburg, Virginia.

18 Green, M. 1987. Energy in Pesticide Manufacture, Distribution, and Use, Energy in Plant Nutrition and Pest Control, ed. Z.R. Helsel, New York, Elsevier, pp. 165-196.

19 Hudson, Charles L. 1982. Energy Requirements for Materials Used in Vehicles Characterized for the Tapcut Project, Argonne National Laboratory, ANL/EES-TM-211.

20 Kellog, R.L., and S. Wallace. 1995. Erosion Estimates and the Effects of Land Use Changes on Soil Savings Estimates - Insights from the 1992 National Resources Inventory, Poster Board Presented at the 50th Annual Meeting of the Soil and Water Conservation Society, August 6-9, 1995, Des Moines, Iowa.

21 Kirk-Othmer. 1982. The Encyclopedia of Chemical Technologies, Vol. 10, "Fertilizers".

22 Lindeburg, M.R. 1988. Engineering Unit Conversions, Professional Publications Inc., Belmont, CA

23 Marland, G., and A. Turhollow. 1990. Carbon Dioxide Emissions from Production and Combustion of Fuel Ethanol from Corn, Oak Ridge National Laboratory, ORNL/TM-11180.

24 Mudahar, M.S. and T.P. Hignett. 1981. Energy and Fertilizer: Policy Implications and Options for Developing Countries, Executive Brief, Technical Bulletin IFDC-T-19, International Fertilizer Development Center, Muscle Shoals, Alabama.

25 Mudahar, M.S. and T.P. Hignett. 1982. Energy and Fertilizer: Policy Implications and Options for Developing Countries, Executive Brief, Technical Bulletin IFDC-T-19, International Fertilizer Development Center, Muscle Shoals, Alabama.

26 Parisi, Frederico. 1983. Energy Balances or Ethanol as a Fuel, Advances in Biochemical Engineering/Biotechnology, 28:42--68 (1983).

27 Pimentel, David (ed.). 1980. Handbook of Energy Utilization in Agriculture, CRC Press, Boca Raton, FL.

28 Pimentel, David et al. 1988. Food Versus Biomass Fuel: Socioeconomic and Environmental Impacts in the United States, Brazil, India, and Kenya, Advances in Food Research, Vol. 32, pp. 185-238, 1988.

29 Pimentel, David. 1991. "Ethanol Fuels: Energy Security, Economics, and the Environment", Journal of Agriculture and Environmental Ethics, V.4, pp1-13, 0893-4282, 1991

30 Shapouri, H, J.A. Duffield, and M.S. Graboski. 1995. Estimating the Net Energy Balance of Corn Ethanol, USDA/ERS, AER-721, Washington, D.C.

31 United States Department of Agriculture. 1994 (revised 1995). Summary Report: 1992 National Resources Inventory, USDA Natural Resources Conservation Service and the Iowa State University Statistical Laboratory.

32 United States Department of Agriculture. 1993. Agricultural Resources: Inputs: Situation and Outlook Report, USDA Economic Research Service, AR-32.

33 United States Department of Agriculture, Economic Research Service. 1994. Agricultural Resource and Environmental Indicators, USDA/ERS, Ag. handbook 705, Washington, D.C.

34 United States Department of Agriculture, National Agricultural Statistics Service, Crop Production: 1994 Summary, Cr Pr 2-1(95), January 1995.

35 United States Department of Agriculture. various. Agricultural Chemical Usage: (yr) Field Crop Summary, USDA National Agricultural Statistics Service, Ag Ch 1(yr).

36 United States Department of Energy, Energy Information Administration. 1994. Manufacturing Consumption of Energy: 1991, DOE/EIA 0512(91).

37 United States Department of Energy, Energy Information Administration. 1994. Emissions of Greenhouse Gases in the U.S.: 1987-1992, DOE/EIA-0573.

38 United States Department of Energy, Energy Information Administration. 1993. Annual Energy Review: 1993, DOE/EIA-0384(93).

39 United States Geological Survey. 1993. Selected Papers on Agricultural Chemicals in Water Resources of the Midcontinental United States, U.S.G.S. Open-File Report 93-418, U.S. G.S. , Denver, CO.

40 U.S. EPA. 1991. Nonroad Engine and Vehicle Emission Study-Report, EPA 460/3-91-02.

41 U.S. EPA. 1991. Nonroad Engine and Vehicle Emission Study-Appendixes (sp): Draft, 21A-2001 (NTIS #PB92-104462).

42 U.S. Department of the Interior, Bureau of Mines. 1994. Mineral Commodity Summaries: 1994

43 United States Environmental Protection Agency. 1995. Compilation of Air Pollutant Emission Factors, AP-42, Fifth Edition.

44 Unnasch, Stefan. 1990. Greenhouse Gas Emission from Ethanol Production and Vehicle Use, Acurex Corp. for the Nat'l Corn Growers Association

45 Watson, R.T. et al. 1990. Greenhouse Gases and Aerosols, in Intergovernmental Panel on Climate Change, Climate Change: The IPCC Scientific Assessment Report Prepared by Working Group I, J.T. Houghton, et al (ed.), UK, 1990.

46 Weast, R.C., and M.J. Astle (ed). 1981. Handbook of Chemistry and Physics, 62nd Edition, CRC Press, Boca Raton, Florida.

47 Weinblatt, Herbert, T.S. Reddy, and Anthonly Turhollow. 1982. Energy and Precious Fuels Requirements of Fuel Alcohol Production, Vol. II, Appendices A and B: Ethanol from Grain, DOE/NASA/0292-1

List of Tables:

21 Energy Use for Seed in Corn Production
22 Energy Use for Lime and Sulfur in Corn Production
23 Total Energy Use in Corn Production
24 Nitrogen Oxide Emissions from Corn Production
25 Pesticide and Nutrient Loss to Surface and Groundwater
26 PM-10 Fugitive Emissions from Corn Production
27 Emissions from Energy Consumption in Nitrogenous Fertilizer Manufacture
28 Emissions from Diesel Consumption in Limestone Production and Farm Input Hauling
29 Emissions from Farm Equipment
30 Emissions from Natural Gas and LPG Use for Corn and Seed Production
31 Unallocated Emissions from Fuels
32 Material resource Requirements for Fertilizer and Herbicide Manufacture
33 Emissions of PM-10 from Crushed Stone Processing Operations
34 Emissions from Phosphate Rock Processing
35 Process Related Emissions from Ammonia Manufacture for Nitrogenous Fertilizers
36 Process Emissions from Urea Manufacture
37 Process Emissions from Ammonium Nitrate Manufacture
38 Process Emissions from Ammonium Phosphate Manufacture
39 Process Emissions from Nitric Acid Manufacture (used in ammonium nitrate manufacture)
40 Process Emissions from the Manufacture of Phosphoric Acid
41 Process Emissions from Sulfuric Acid Manufacture (used in phosphoric acid manufacture)
42 Air Emissions from Pesticide Use

Summary Output:

| Allocated LCI components | | | Units | Quantity | DQI | Notes: |
|---|---|---|---|---|---|---|
| Air | Fertilizer N20 | | lb/bu | 0.0132 | 3 | Survey of study results. |
| | Fertilizer NO | | lb/bu | 0.0081 | 1 | Based on only one study. |
| | NOx | | lb/bu | 4.26E-02 | 2 | Some general emisson factors used |
| | SOx | | lb/bu | 2.03E-02 | 2 | Some general emisson factors used |
| | PM-10 | | lb/bu | 3.62E-01 | 3 | Driven by fugitive emissions from tilling for which current data is available. |
| | CO | | lb/bu | 1.53E-01 | 4 | Driven by CO emission from gas tractors for which current data is available. |
| | CO2 | | lb/bu | 6.93E+00 | 4 | Good quality data |
| | Non-Methane Organic C | | lb/bu | 2.33E-02 | 3 | Dominated by VOC's used in pesticides. Relatively well characterized. |
| | Methane | | lb/bu | 1.98E-05 | 2 | Some general emisson factors used |
| | Particulate | | lb/bu | 4.48E-03 | 2 | Some general emisson factors used |
| | Hydrocarbons | | lb/bu | 1.00E-02 | 3 | Fairly current and specific data on farm machinery emissions. |
| | Aldehydes | | lb/bu | 4.70E-04 | 3 | Fairly current and specific data on farm machinery emissions. |
| | Ammonia | | lb/bu | 1.42E-02 | 2 | Dominated by emissions from ammonium nitrate manufacture, for which factors given as a very broad range. Thus point estimate may be poor. |
| | Nitric Acid | | lb/bu | 1.97E-04 | 2 | Dominated by emissions from ammonium nitrate manufacture, for which factors given as a very broad range. Thus point estimate may be poor. |
| | Fluoride | | lb/bu | 1.79E-05 | 4 | AP-42 Emission Factor based. Data quality rating excellent. |
| | Acid Mist | | lb/bu | 1.01E-03 | 2 | AP-42 Emission Factor based. Data quality rating poor. |
| | Herbicides | | lb/bu | 5.06E-03 | 2 | Emission factor rating poor. |
| | | Alachlor | lb/bu | 1.01E-03 | 2 | Emission factor rating poor. |
| | | Atrazine | lb/bu | 1.86E-03 | 2 | Emission factor rating poor. |
| | | Metalachlor | lb/bu | 1.23E-03 | 2 | Emission factor rating poor. |
| | | Cyanazine | lb/bu | 9.62E-04 | 2 | Emission factor rating poor. |
| | Insecticides | | lb/bu | 8.01E-04 | 2 | Emission factor rating poor. |
| | | Fonofos | lb/bu | 1.49E-04 | 2 | Emission factor rating poor. |
| | | Turbufos | lb/bu | 3.95E-04 | 2 | Emission factor rating poor. |
| | | Chlorpyrifos | lb/bu | 2.57E-04 | 2 | Emission factor rating poor. |
| Water | Herbicides | | lb/bu | 1.97E-04 | 3 | These four herbicides make up 80% of the total herbicide use (out of a total of 26 herbicides) in corn production |
| | | Alachlor | lb/bu | 8.82E-06 | | |
| | | Atrazine | lb/bu | 9.55E-05 | | |
| | | Metalachlor | lb/bu | 3.88E-05 | | |

| | | | | | |
|---|---|---|---|---|---|
| | Cyanazine | lb/bu | 5.36E-05 | | |
| Insecticides | | lb/bu | 1.67E-05 | 2 | There is little data on insecticide loss |
| | Fonofos | lb/bu | 2.57E-06 | | These three insecticides make up 75% |
| | Turbufos | lb/bu | 6.81E-06 | | of total insectide use in corn production. |
| | Chlorpyrifos | lb/bu | 7.34E-06 | | |
| Nitrates (as nitrogen) | | lb/bu | 0.16 | 3 | Other sources of nitrogen contribute to nitrate loading |
| Phosphorous | | lb/bu | 3.92E-03 | | |
| Potassium | | lb/bu | 0.02 | | |
| Resource CoN.G. | | Btu/bu | 28,391 | 4 | Energy use estimates derived from current data and are consistent with other results. |
| Diesel | | Btu/bu | 11,393 | 4 | Energy use estimates derived from current data and are consistent with other results. |
| LPG | | Btu/bu | 3,210 | 4 | Energy use estimates derived from current data and are consistent with other results. |
| Coal | | Btu/bu | 522 | 4 | Energy use estimates derived from current data and are consistent with other results. |
| Oil | | Btu/bu | 1,870 | 4 | Energy use estimates derived from current data and are consistent with other results. |
| Gasoline | | Btu/bu | 3,621 | 4 | Energy use estimates derived from current data and are consistent with other results. |
| Electricity | | Kwh/bu | 0.494 | 4 | Energy use estimates derived from current data and are consistent with other results. |
| Total Fuel | | Btu/bu | 49,007 | | |
| Limestone | | lb/bu | 1.28 | 4 | Current data but some conflicting estimates. |
| Sulfur | | lb/bu | 0.436 | 5 | Current data. |
| Water | | gallons/bu | 8,863 | 3 | Derived from average irrigation practices. |
| Phosphate Rock | | lb/bu | 1.253 | 5 | Current data. |
| Potassium Chloride | | lb/bu | 0.367 | 5 | Current data. |
| Soil | | lb/bu | 96 | 3 | Total Loss of Soil. See Table 4. |

Conversion Factors

| Unit from | Unit to | Multiplier | Name | Source: | |
|---|---|---|---|---|---|
| bu | lb | 56 | lb_bu | | |
| Hectares | acre | 2.47 | acre_hect | 22 | |
| kg | lb | 2.20 | lb_kg | 22 | |
| hectares | sq. meters | 10,000 | sqmeters_hect | 22 | |
| meter | feet | 3.28 | feet_meter | 22 | |
| short tons | lb | 2,000 | lb_shortton | 22 | |
| metric tons | kg | 1,000 | kg_mton | 22 | |
| kcal | btu | 3.97 | btu_kcal | 22 | |
| Joules | btu | 9.47E-04 | btu_joule | 22 | |
| Gallons Etha | lb | 6.58 | lb_gallon | 46 | Specific Gravity = .7893 |
| Gallons Etha | bu | 0.4 | bu_gallon | 12 | Depending on plant and process may range from .385 to .40. |
| Hectares | Sq. cm | 1.00E+08 | sqcm_ha | 22 | |
| cubic cm | liters | 0.001 | liters_ccm | 22 | |
| liters | gallons | 0.264 | gallons_liter | 22 | |
| sq mile | acres | 640 | acres_sqmile | 22 | |
| metric tons | short tons | 1.102 | shortton_metricto | 22 | |
| barrels | gallons | 42 | gallons_barrel | 22 | |
| kg | grams | 1,000 | grams_kg | 22 | |
| cubic foot na | btu | 1,032 | btu_cubicft | 38 | |
| barrel distilla | million btu | 5.825 | btu_barreloil | 38 | |
| barrel motor | million btu | 5.253 | btu_barrelgas | 38 | |
| Short ton coa | million btu | 22.25 | Btu_toncoal | 38 | |
| Barrel LPG | million btu | 3.614 | Btu_barrellpg | 38 | 86,048 |
| Gallons Wate | lb | 8.337 | lb_gallonw | 22 | |

Molecular W Element/ComName Wt. Defined Name

| | | |
|---|---|---|
| H | Hydrogen | 1.008 |
| Ca | Calcium | 40.08 |
| O | Oxygen | 16.00 |
| S | Sulfur | 32.06 |
| C | Carbon | 12.01 |
| Cl | Chlorine | 35.45 |
| K | Potassium | 39.10 |
| P | Phosphorus | 30.97 |
| N | Nitrogen | 14.01 |
| K2O | Potash | 94.20 |
| KCl | Muriate of Potash | 74.56 |
| CO2 | Carbon Dioxide | 44.01 |
| CaSO4 | Calcium Sulfate | 136.14 |
| H2SO4 | Sulfuric Acid | 98.07 |
| P2O5 | Phosphoric Acid | 141.94 |
| HNO3 | Nitric Acid | 63.01 |
| NH4NO3 | Ammonium Nitrate | 80.04 |

| | | |
|---|---|---|
| Ratio CO2:C | 3.66 | carbon_ratio |
| Ratio K2O:KCl | 1.26 | Potassium_ratio |
| Ratio H2SO4:S | 3.06 | Sulfur_acid |
| Ratio S:P2O5 | 0.23 | sulfur_Pratio |
| Ratio 2N:NH4NO3 | 0.35 | N_ammonitrate |
| Ratio HNO3:NH4NO3 | 0.79 | |
| Ratio N:NH3 | 0.82 | Ammonia_ratio |
| Ratio H2SO4:P2O5 | 0.69 | |

Calculations

Table 1 Corn Yield per Acre Planted (k acres and bushels/acre)

United States Department of Agriculture
National Agricultural Statistics Service
Crop Production: 1994 Summary
Cr Pr 2-1(95)
January 1995 Area in thousands of acres

LCI component

| | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 10 - Year Avera | 6 - Year Aver | 4 - Year Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Area Planted | 83,398 | 76,580 | 66,200 | 67,717 | 72,322 | 74,166 | 75,957 | 79,311 | 73,235 | 79,158 | 74,804 | 75,692 | 76,915 |
| Area Harvest | 75,209 | 68,907 | 59,505 | 58,250 | 64,783 | 66,952 | 68,822 | 72,077 | 62,921 | 72,917 | 67,034 | 68,079 | 69,184 |
| Area Harvest | 7,155 | 6,418 | 5,994 | 8,301 | 6,606 | 6,123 | 6,140 | 6,069 | 6,831 | 5,563 | 6,520 | 6,222 | 6,151 |
| Total Area H | 82,364 | 75,325 | 65,499 | 66,551 | 71,389 | 73,075 | 74,962 | 78,146 | 69,752 | 78,480 | 73,554 | 74,301 | 75,335 |
| Fraction of A | 98.76% | 98.36% | 98.94% | 98.28% | 98.71% | 98.53% | 98.69% | 98.53% | 95.24% | 99.14% | 98.32% | 98.14% | 97.90% |
| Yield (Corn fo | 118 | 119.40 | 119.80 | 84.6 | 116.30 | 118.5 | 108.6 | 131.5 | 100.7 | 138.60 | 115.6 | 119.0 | 119.9 |
| Adjusted Yiel | 116.5 | 117.4 | 118.5 | 83.1 | 114.8 | 116.8 | 107.2 | 129.6 | 95.9 | 137.4 | 113.7 | 116.9 | 117.5 |

Notes: Data in bolded rows are from the USDA publication. Since energy is invested in all planted acreage, corn yields are adjusted to the yield per planted acre by multiplying by the fraction of planted acres harvested in any given year. The average yield has been increasing over time. In order to most accurately describe current yields, average yields over the past 20 years can be fit with a simple linear model. The data are converted to a base year of 1975, so that year 1 represents 1975, and year 20 represent 1994. Based on this model (presente 120.54 bu/acre.
This value is stored in the variable yield, and is used throughout this spreadsheet.

| Model | R squared = .3859 | F test |
|---|---|---|
| Intercept | 89 | 0.0001 |
| Year (1 - 20) | 1.68 | 0.0035 |

| Predicted YieQuantity | | Units | Adjusted Yield (to account for fraction of planted acreage that is harvested) |
|---|---|---|---|
| 1992 | 119.2 | Bu/acre | 117.2 |
| 1993 | 120.9 | Bu/acre | 118.9 |

1994 122.6 Bu/acre 120.5

Table 2 Chemical Usage in Corn Production

(1) Agricultural Chemical Usage: (Year) Field Crop Summary
United States Department of Agriculture, National Agricultural Statistics Service
Ag Ch 1 (yr)

| LCI component | | Raw/ Input Quan. | Raw/ Input Quan. | Raw/ Input Quan. | Raw/ Input Quan. | DQI | Transformed Quan. | Transformed Quan. | Transformed Quan. | Transformed Quan. | Raw Average | Transformed Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | | 1991 | 1992 | 1993 | 1994 | | 1991 | 1992 | 1993 | 1994 | | |
| Raw/Input Units | | (MM lbs) | (MM lbs) | (MM lbs) | (MM lbs) | | (lbs/acre) | (lbs/acre) | (lbs/acre) | (lbs/acre) | (MM lbs) | (lbs/acre) |
| Fertilizers | | | | | | | | | | | | |
| | Nitrogen | 8,447 | 8,902 | 7,956 | 7,856 | 10 | 123 | 125 | 121 | 126 | 8,290 | 123.7 |
| | Phosphate | 3,331 | 3,344 | 2,995 | 2,992 | 10 | 49 | 47 | 46 | 48 | 3,166 | 47.2 |
| | Potash | 3,910 | 3,950 | 3,519 | 3,603 | 10 | 57 | 55 | 54 | 58 | 3,746 | 55.9 |
| | | (thousand lbs | (thousand lbs) | (thousand lbs | (thousand lbs) | | (lbs/acre) | (lbs/acre) | (lbs/acre) | (lbs/acre) | | |
| Herbicides | | | | | | | | | | | | |
| | 2,4-D | 2,800 | 2,832 | 3,586 | 3,631 | 10 | 0.041 | 0.040 | 0.055 | 0.058 | 3,212 | 0.048 |
| | Acetochlor | | | | 7,447 | 10 | 0.000 | 0.000 | 0.000 | 0.119 | 1,862 | 0.030 |
| | Alachlor | 37,174 | 40,129 | 32,078 | 21,325 | 10 | 0.542 | 0.562 | 0.488 | 0.341 | 32,677 | 0.483 |
| | Ametryn | 59 | 146 | | | 10 | 0.001 | 0.002 | 0.000 | 0.000 | 51 | 0.001 |
| | Atrazine | 52,060 | 54,939 | 49,553 | 45,412 | 10 | 0.759 | 0.769 | 0.754 | 0.727 | 50,491 | 0.752 |
| | Bentazon | 478 | 550 | 497 | 584 | 10 | 0.007 | 0.008 | 0.008 | 0.009 | 527 | 0.008 |
| | Bromoxynil | 1,344 | 1,389 | 1,364 | 1,446 | 10 | 0.020 | 0.019 | 0.021 | 0.023 | 1,386 | 0.021 |
| | Butylate | 8,478 | 8,117 | 5,441 | 2,117 | 10 | 0.124 | 0.114 | 0.083 | 0.034 | 6,038 | 0.088 |
| | Cyanazine | 23,161 | 26,691 | 26,453 | 27,689 | 10 | 0.338 | 0.374 | 0.403 | 0.443 | 25,999 | 0.389 |
| | Dicamba | 3,556 | 5,068 | 4,598 | 6,322 | 10 | 0.052 | 0.071 | 0.070 | 0.101 | 4,886 | 0.073 |
| | Dimethenamid | | | | 2,241 | 10 | 0.000 | 0.000 | 0.000 | 0.036 | 560 | 0.009 |
| | EPTC | 14,355 | 10,594 | 11,098 | 6,124 | 10 | 0.209 | 0.148 | 0.169 | 0.098 | 10,543 | 0.156 |
| | Flumetsulam | | | | 52 | 10 | 0.000 | 0.000 | 0.000 | 0.001 | 13 | 0.000 |
| | Glyphosate | 1,156 | 746 | 1,973 | 1,776 | 10 | 0.017 | 0.010 | 0.030 | 0.028 | 1,413 | 0.021 |
| | Imazethapyr | | | 11 | 37 | 10 | 0.000 | 0.000 | 0.000 | 0.001 | 12 | 0.000 |
| | Linuraon | 93 | 96 | | | 10 | 0.001 | 0.001 | 0.000 | 0.000 | 47 | 0.001 |
| | Metolachlor | 38,792 | 41,327 | 39,026 | 39,213 | 10 | 0.565 | 0.579 | 0.594 | 0.627 | 39,590 | 0.591 |
| | Metribuzin | | | 46 | 41 | 10 | 0.000 | 0.000 | 0.001 | 0.001 | 22 | 0.000 |
| | Nicosulfuron | 75 | 140 | 165 | 249 | 10 | 0.001 | 0.002 | 0.003 | 0.004 | 157 | 0.002 |
| | Paraquat | 201 | 423 | 630 | 400 | 10 | 0.003 | 0.006 | 0.010 | 0.006 | 414 | 0.006 |
| | Pendimentalin | 2,745 | 3,091 | 2,825 | 1,806 | 10 | 0.040 | 0.043 | 0.043 | 0.029 | 2,617 | 0.039 |
| | Primisulfuron | 29 | 30 | 40 | 47 | 10 | 0.000 | 0.000 | 0.001 | 0.001 | 37 | 0.001 |
| | Propachlor | 1,456 | 1,506 | 1,260 | 1,184 | 10 | 0.021 | 0.021 | 0.019 | 0.019 | 1,352 | 0.020 |
| | Simazine | 1,081 | 1,147 | 1,118 | 972 | 10 | 0.016 | 0.016 | 0.017 | 0.016 | 1,080 | 0.016 |
| | Tridiphane | 264 | 123 | | 66 | 10 | 0.004 | 0.002 | 0.000 | 0.001 | 113 | 0.002 |
| | Trifluralin | 111 | | 114 | | 10 | 0.002 | 0.000 | 0.002 | 0.000 | 56 | 0.001 |
| | Total Herbicide | 189,468 | 199,084 | 181,876 | 170,181 | | 2.76 | 2.79 | 2.77 | 2.72 | 185,152 | 2.760 |
| | | (thousand lbs | (thousand lbs) | (thousand lbs | (thousand lbs) | | (lbs/acre) | (lbs/acre) | (lbs/acre) | (lbs/acre) | | |
| Insecticides | | | | | | | | | | | | |
| | Bifenthrin | 14 | 4 | | | 10 | 0.0002 | 0.0001 | 0.0000 | 0.0000 | 5 | 0.0001 |
| | Bacillus thur. | 2,094 | | | 326 | 10 | 0.0305 | 0.0000 | 0.0000 | 0.0052 | 605 | 0.0089 |
| | Carbofuran | 2,278 | 1,648 | 1,133 | 326 | 10 | 0.0332 | 0.0231 | 0.0172 | 0.0052 | 1,346 | 0.0197 |
| | Chlorpyrifos | 6,716 | 6,247 | 5,584 | 5,206 | 10 | 0.0979 | 0.0875 | 0.0850 | 0.0833 | 5,938 | 0.0884 |
| | Diazinon | 116 | 74 | | | 10 | 0.0017 | 0.0010 | 0.0000 | 0.0000 | 48 | 0.0007 |
| | Dimethoate | 78 | 74 | | | 10 | 0.0011 | 0.0010 | 0.0000 | 0.0000 | 38 | 0.0005 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Esfenvalerate | 12 | 8 | | | 10 | 0.0002 | 0.0001 | 0.0000 | 0.0000 | 5 | 0.0001 |
| Flucythrinate | 6 | | | | 10 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 2 | 0.0000 |
| Fonofos | 2,890 | 2,044 | 1,876 | 1,549 | 10 | 0.0421 | 0.0286 | 0.0286 | 0.0248 | 2,090 | 0.0310 |
| Methyl Parathion | 812 | 557 | 635 | 738 | 10 | 0.0118 | 0.0078 | 0.0097 | 0.0118 | 686 | 0.0103 |
| Permethrin | 207 | 202 | 155 | 222 | 10 | 0.0030 | 0.0028 | 0.0024 | 0.0036 | 197 | 0.0029 |
| Phorate | 1,306 | 990 | 1,448 | 895 | 10 | 0.0190 | 0.0139 | 0.0220 | 0.0143 | 1,160 | 0.0173 |
| Propargite | 146 | | | | 10 | 0.0021 | 0.0000 | 0.0000 | 0.0000 | 37 | 0.0005 |
| Tefluthrin | 244 | 187 | 246 | 242 | 10 | 0.0036 | 0.0026 | 0.0037 | 0.0039 | 230 | 0.0034 |
| Terbufos | 5,986 | 6,309 | 5,561 | 4,270 | 10 | 0.0873 | 0.0884 | 0.0846 | 0.0683 | 5,532 | 0.0821 |
| Trimethacarb | 121 | 132 | | | 10 | 0.0018 | 0.0018 | 0.0000 | 0.0000 | 63 | 0.0009 |
| Total Insecticide | | | | | | | | | | 17,979 | 0.2670 |

Notes: The data given below indicates the number of states from which the agricultural chemical usage data was developed, and the percentage of planted area which those states represent for corn.

| Year | 1991 | 1992 | 1993 | 1994 | |
|---|---|---|---|---|---|
| States Covered | 17 | 17 | 16 | 10 | 15 |
| Percentage of Area | 90% | 90% | 90% | 79% | 87% |
| Area Planted (MM Acres) | 68.6 | 71.4 | 65.7 | 62.5 | 67.05 |

---

Table 3 Seed Consumption

United States Department of Agriculture, Economic Research Service
Agricultural Resources, Inputs: Situation and Outlook Report, AR-32, 1993

United States Department of Agriculture
National Agricultural Statistics Service
Crop Production: 1994 Summary
Cr Pr 2-1(95)
January 1995

| LCI Compon Crop Year | Seed | Seed (lb) | Seed (MMBu | Area Planted | Seed/acre | Seed/acre | Seed/bu |
|---|---|---|---|---|---|---|---|
| Units | Th. short ton | lb | million bushe | thousand acre | lb/acre | kg/ha | lb/bu |
| 1989/90 | 529 | 1,058,000,000 | 18.89 | 74,166 | 14.27 | 15.99 | 0.118 |
| 1990/91 | 540 | 1,080,000,000 | 19.29 | 75,957 | 14.22 | 15.94 | 0.118 |
| 1991/92 | 566 | 1,132,000,000 | 20.21 | 79,311 | 14.27 | 16.00 | 0.118 |
| 1992/93 | 524 | 1,048,000,000 | 18.71 | 73,235 | 14.31 | 16.04 | 0.119 |
| Average | | | | | 14.27 | 15.99 | 0.118 |

Notes: Seed use in bold from source 1, area planted in bold from source 2, the data for which are in table 1. Four year average value converted to seed use per bushel using the estimated yield in table 1.

---

Table 4 Erosion from Cropland and Corn Cropland

(1) United States Department of Agriculture. 1994 (revised 1995). Summary Report: 1992 National Resources Inventory, USDA Natural Resources Conservation Service and the Iowa State University Statistical Laboratory.

(2) Kellog, R.L., and S. Wallace. 1995. Erosion Estimates and the Effects of Land Use Changes on Soil Savings Estimates - Insights from the 1992 National Resources Inventory, Poster Board Presented at the 50th Annual Meeting of the Soil and Water Conservation Society, August 6-9, 1995, Des Moines, Iowa.

LCI Component Erosion weighted by production

Erosion By State and Type (1)

| Units | Raw/ Input Quan. (tons/acre/yr) | Raw/ Input Quan. tons/acre/yr) | Raw/ Input Quan. (tons/acre/yr) | (million bushe | (million bushels) | | Transformed Quan. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| State | Sheet/Rill Erosion | Wind Erosion | Total Erosion | 1994 Producti | Cumulative | Cum. Fraction | Sheet/Rill Ero | Wind Erosion | Total Erosion | Erosion per Bushel (tons/bu) | Erosion per Bushel (lb/bu) |
| Iowa | 5.6 | 1.4 | 7 | 1,930,400 | 1,930,400 | 19.11% | 10,810,240 | 2,702,560 | 13,512,800 | | |
| Illinois | 4.4 | 0 | 4.4 | 1,786,200 | 3,716,600 | 36.79% | 7,859,280 | 0 | 7,859,280 | | |
| Nebraska | 3.6 | 1.7 | 5.3 | 1,153,700 | 4,870,300 | 48.21% | 4,153,320 | 1,961,290 | 6,114,610 | | |
| Minnesota | 2.4 | 6.3 | 8.7 | 915,900 | 5,786,200 | 57.27% | 2,198,160 | 5,770,170 | 7,968,330 | | |
| Indiana | 3.4 | 0.4 | 3.8 | 858,240 | 6,644,440 | 65.77% | 2,918,016 | 343,296 | 3,261,312 | | |
| Ohio | 3.3 | 0.1 | 3.4 | 486,500 | 7,130,940 | 70.58% | 1,605,450 | 48,650 | 1,654,100 | | |
| Wisconsin | 4.1 | 0.3 | 4.4 | 437,100 | 7,568,040 | 74.91% | 1,792,110 | 131,130 | 1,923,240 | | |
| South Dakota | 2.3 | 2.7 | 5 | 367,200 | 7,935,240 | 78.54% | 844,560 | 991,440 | 1,836,000 | | |
| Kansas | 2.3 | 2.1 | 4.4 | 304,590 | 8,239,830 | 81.56% | 700,557 | 639,639 | 1,340,196 | | |
| Total | 31.4 | 15 | 46.4 | 10,103,000 | | | 32,881,693 | 12,588,175 | 45,469,868 | | |
| Average | 3.49 | 1.67 | 5.16 | | | | 3.25 | 1.25 | 4.50 | 0.04 | 74.68 |
| | | | | | | | 54.00 | 20.67 | 74.68 | | |

| Erosion by C | Raw/ Input Quan. | Raw/ Input Quan. | Raw/ Input Quan. | |
|---|---|---|---|---|
| | Sheet/Rill Erosion | Wind Erosion | Total Erosion | Units |
| Land Planted | 4.4 | 1.3 | 5.7 | tons/acre/year |
| Highly Erodib | 11.2 | 2.2 | 13.4 | tons/acre/year |
| Not Highly Er | 2.5 | 1.1 | 3.6 | tons/acre/year |
| All Corn Land | 4.3 | 1.5 | 5.8 | tons/acre/year |
| Highly Erodib | 10.8 | 2.3 | 13.1 | tons/acre/year |
| Not Highly Er | 2.5 | 1.2 | 3.7 | tons/acre/year |
| All Corn Land | 71.35 | 24.89 | 96.23 | lb/bu |

Notes: Bob Kellog provided this disaggregated data. Soil loss cannot be treated simply as a resource cost, since soil is naturally regenerated over time. This is usually quantified as the soil loss tolerance, usually somewhere between 4 and 5 tons/acre/year. The corn land soil loss estimate used here is slightly above this value, indicating that some degradation of corn cropland is occurring. Soil losses have been decreasing steadily in the past decade, however, indicating that average losses will soon be in the soil loss tolerance range.

---

Table 5 Water Use in Irrigation


(1) United States Department of Agriculture. 1994 (revised 1995). Summary Report: 1992 National Resources Inventory, USDA Natural Resources Conservation Service and the Iowa State University Statistical Laboratory.

(2) Ali, Mir, and W. McBride. 1994. Corn: State-Level Production Costs, Characteristics, and Input Use, 1991, USDA/ERS, SB-891.

(3) United States Department of Agriculture, National Agricultural Statistics Service, Crop Production: 1994 Summary, Cr Pr 2-1(95), January 1995.

(4) Pimentel, David (ed.). 1980. Handbook of Energy Utilization in Agriculture, CRC Press, Boca Raton, FL.


| | Weighting Data | | | Raw/ Input Quan. (acres) | Raw/ Input Quan. (acres) | Raw/ Input Quan. (acres) | | Requirements (4) (cm) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| State | 1994 Production (3) | Cumulative | Cum. Fraction | Irrigated | Non-Irrigated | Total | Percentage | | Weighted by % irrigated | Times Production |

| | (million bushels) | (million bushels) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Iowa | 1,930,400 | 1,930,400 | 19.11% | 143.9 | 23,222 | 23,366 | 0.00% | | 52.07 | 0.00 | 0 |
| Illinois | 1,786,200 | 3,716,600 | 36.79% | 196 | 22,984 | 23,180 | 0.00% | | 52.07 | 0.00 | 0 |
| Nebraska | 1,153,700 | 4,870,300 | 48.21% | 6923.2 | 10,510 | 17,433 | 76.00% | | 50.80 | 38.61 | 44,542,050 |
| Minnesota | 915,900 | 5,786,200 | 57.27% | 434 | 18,312 | 18,746 | 2.32% | | 52.07 | 1.21 | 1,104,098 |
| Indiana | 858,240 | 6,644,440 | 65.77% | 174.2 | 12,582 | 12,756 | 8.00% | | 52.07 | 4.17 | 3,575,085 |
| Ohio | 486,500 | 7,130,940 | 70.58% | 27.5 | 10,144 | 10,172 | 0.00% | | 52.07 | 0.00 | 0 |
| Wisconsin | 437,100 | 7,568,040 | 74.91% | 334 | 6,714 | 7,048 | 5.00% | | 52.07 | 2.60 | 1,137,990 |
| South Dakota | 367,200 | 7,935,240 | 78.54% | 389.4 | 13,514 | 13,904 | 29.00% | | 52.07 | 15.10 | 5,544,830 |
| Michigan | 260,910 | 8,196,150 | 81.13% | 3209 | 21,698 | 24,907 | 9.00% | (kansas) | 53.34 | 4.80 | 1,252,525 |
| Total | 10,103,000 | | | 11,831 | 139,680 | 151511.1 | 7.81% | | | 66.48 | 57,156,576 |

Note: This calculation was originally made form reference 1. More accurate data was available in reference 2, however, so where applicable these values were substituted into the fraction of acreage irrigated column. In general the estimates from reference 1 were good for states using little or no irrigation, but somewhat low for states using significant amounts of irrigation. Data from reference 2 has been retained as it is used for one state, Minnesota, for which a value is not given in reference 2. Irrigation rates are taken from reference 4 for Nebraska and and Kansas. The average average of these two values is applied to the other states. From this data a weighted average water use value is calculated, which represents the average amount of water used in irrigation per bushel of corn grown. Thus the value is far below the actual amount used in irrigated corn, and reflects the fact that most corn is not irrigated.

| Weighted | |
|---|---|
| Average (cm) | 6.97 |
| cubic cm/Ha | 697,358,837 |
| liters/ha | 697,359 |
| gallons/ha | 2,639,811 |
| gallons/acre | 1,068,300 |
| gallons/Bu | 8,863 |

Table 6 Lime and Sulfur Consumption

(1) United States Department of Agriculture. 1993. Agricultural Resources: Inputs: Situation and Outlook Report, USDA Economic Research Service, AR-32.

| | Area (MM acres) | Applied (%) | Rate (lb/acre) | Total (MM lbs) | Rate (adj) (lb/acre) | Rate Planted (lb/acre) | Rate (lb/Bu) | Energy (Btu/lb) | Energy Btu/bu) |
|---|---|---|---|---|---|---|---|---|---|
| Lime | 62.85 | 4% | 3800 | 9553.2 | 152 | 154.60 | 1.28 | 568 | 727.90 |
| Sulfur | 62.85 | 11% | 11 | 76.0485 | 1.21 | 1.23 | 0.01 | 1997 | 20.39 |

Notes: The ERS publishes information on the use of lime and sulfur in corn production. They give an application rate in lb/acre for acreage that is treated. This can be converted into an overall average application rate per acre by dividing total applied material by the total planted area. This value must then be converted to account for the fact that not all planted acreage is harvested. This is done by dividing by the harvested fraction (defined variable fraction). Finally the value is converted to units of lb/bushel using the average yield (defined variable yield).

Table 7 Energy Use in the Production of Fertilizer

(1) Blankenhorn, Paul R., et al. 1986. Net Financial and Energy Analyses for Producing Populus Hybrid Under Four Management Strategies: First Rotation, Oak Ridge Nat'l Laboratory, ORNL/Sub/79-07928/1.

(3) The Fertilizer Institute. 1982. The Fertilizer Handbook

(4) Bhat, Mahadev G., Burton C. English, Anthony Turhollow, and Herzron Nyangito. 1993. Energy Use in Synthetic Agricultural Inputs: Revisited, Report prepared by the Department of Agricultural Economics and Rural Sociology, The University of Tennessee, Knoxville, for Biofuels Feedstock Development Program Environmental Sciences Division, Oak Ridge National Laboratory, ORNL/Sub/90-99732/2.

(5) Mudahar, M.S. and T.P. Hignett. 1981. Energy and Fertilizer: Policy Implications and Options for Developing Countries, Executive Brief, Technical Bulletin IFDC-T-19, International Fertilizer Development Center, Muscle Shoals, Alabama.

(6) Mudahar, M.S. and T.P. Hignett. 1982. Energy and Fertilizer: Policy Implications and Options for Developing Countries, Executive Brief, Technical Bulletin IFDC-T-19, International Fertilizer Development Center, Muscle Shoals, Alabama.

(7) The Fertilizer Institute. 1987. Fertilizer Energy Use Survey.

(8) Shapouri, H, J.A. Duffield, and M.S. Graboski. 1995. Estimating the Net Energy Balance of Corn Ethanol, USDA/ERS, Economic Report Number 721, Washington, D.C.

(9) Kirk-Othmer. 1982. The Encyclopedia of Chemical Technologies, Vol. 10, "Fertilizers".

Energy Requirements for Fertilizer Production (GJ/metric ton fertilizer)

| | Natural Gas | Electricity | Oil | Steam | Exported Stea | Total |
|---|---|---|---|---|---|---|
| Anhydrous A | 40.79 | 1.1 | 0 | 0 | 0.38 | 41.51 |
| Urea | 26.02 | 2.55 | 0 | 3.7 | 0.81 | 31.46 |
| Nitrogen Solu | 16.11 | 1.02 | 0 | 0.63 | 0.37 | 17.39 |
| Triple Superp | 0.54 | 2.51 | 0.55 | 1.89 | 2.35 | 3.14 |
| Potash (as K | 2.69 | 2.11 | 0 | 0 | 0 | 4.8 |

Notes: Taken from Table 16 of reference 4 (p. 26).

Energy Requirements for Fertilizer Production (Btu/lb except electricity, which is kwh/lb)

| | Natural Gas | Electricity | Oil | Steam | Exported Stea | Total (Btu/lb) | Total (kwh/lb) |
|---|---|---|---|---|---|---|---|
| Anhydrous A | 17,523 | 0.047 | 0 | 0 | 163 | 17,360 | 0.047 |
| Urea | 11,178 | 0.110 | 0 | 1,590 | 348 | 12,420 | 0.110 |
| Nitrogen Solu | 6,921 | 0.044 | 0 | 271 | 159 | 7,033 | 0.044 |
| Triple Superp | 232 | 0.108 | 236 | 812 | 1,010 | 271 | 0.108 |
| Potash (as K | 1,156 | 0.091 | 0 | 0 | 0 | 1,156 | 0.091 |

Notes: Reference 7 gives the original survey data, and says that electricity is converted to btu using the convention of 10,000 btu/kwh (i.e. accounting for losses). I have converted back to kwh.

Nutrient Content of Fertilizers

| | | | Source: |
|---|---|---|---|
| Anhydrous A | 82% | Nitrogen | 4 |
| Urea | 46% | Nitrogen | 4 |
| Nitrogen Solu | 30% | Nitrogen | 4 |
| Triple Superp | 46% | P2O5 | 4 |
| Potash (as K | 100% | K2O | 4 |

Notes: Reference 4 uses these nutrient contents. Reference 3 uses 44 to 46% for triple superphosphate, and 28 to 32% for nitrogen solutions. We follow the convention of reference 4.

Energy Requirements for Fertilizer Production (Btu/lb nutrient)

| | Natural Gas | Electricity | Oil | Steam | Exported Stea | Fuel Total (Btu/lb) | Electricity Total (kwh/lb | Electricity (Btu/lb) | Total (Btu/lb) |
|---|---|---|---|---|---|---|---|---|---|
| Anhydrous A | 21,370 | 0.058 | 0 | 0 | 199 | 21,171 | 0.058 | 576 | 21,747 |
| Urea | 24,300 | 0.238 | 0 | 3,455 | 756 | 26,999 | 0.238 | 2,381 | 29,381 |
| Nitrogen Solu | 23,069 | 0.146 | 0 | 902 | 530 | 23,442 | 0.146 | 1,461 | 24,902 |
| Triple Superp | 504 | 0.234 | 514 | 1,765 | 2,195 | 588 | 0.234 | 2,344 | 2,932 |
| Potash (as K | 1,156 | 0.091 | 0 | 0 | 0 | 1,156 | 0.091 | 906 | 2,062 |

Notes: Reference 8 cites the Fertilizer Institute for energy consumption estimates of 22,159 Btu/lb nitrogen, 4,175 Btu/lb P2O5, and 1,245 Btu/lb potash. The nitrogen estimate is close to what reference 4 gets here, but differs significantly for the other fertilizers. Examination of reference 7 reveals that the estimate for potash seems to come from a 1985 survey by the Fertilizer Institute. The value given is 2,489 kbtu/ton potash. This converts to 1,245 Btu/lb of potash. Reference 4 uses this data, plus fuel breakouts from a 1979 survey, but then converts to K2O assuming that the energy use value is for muriate of potash, and that muriate of potash is 60% K2O. This yields our value of 2,065 Btu/lb K2O. Since most references cite potash consumption for agricultural uses in terms of weight of K2O, it is not clear whether reference 8 has used an appropriate energy intensity figure.

Estimating energy use in phosphate production is confused by the fact that sulfuric acid production is highly exothermic. If all of this energy is counted towards phosphoric acid production, in some cases the total energy use is still negative. The estimates given in reference 7, and used by reference 4 seem to exclude energy use in sulfur mining. Reference 3 however, includes energy use in sulfur mining, and cites a total energy consumption

of 7,200 btu/lb $P_2O_5$ for triple superphosphate. Reference 9 also gives a fairly high figure of 5,500 btu/lb $P_2O_5$ for triple superphosphate. Some estimates are given below.

Energy Intensity of Phosphate Fertilizer Production

| Raw Input Qu | Units | Source | Tranformed Inpu | Units | Electricity | Natural Gas | Oil | Units |
|---|---|---|---|---|---|---|---|---|
| 7,200 | Btu/lb $P_2O_5$ | (3) | 7,200 | Btu/lb $K_2O_5$ | | | | |
| 2,300 | kcal/kg $P_2O_5$ | (1) | 4,140 | Btu/lb $K_2O_5$ | | | | |
| 12.79 | GJ/ton $P_2O_5$ | (9) | 5,495 | Btu/lb $K_2O_5$ | | | | |
| 4,175 | Btu/lb $P_2O_5$ | (8) | 4,175 | Btu/lb $K_2O_5$ | 1,962 | 1,086 | 1,127 | Btu/lb |
| | | | | | 0.196 | | | kwh/lb |

Notes: Reference 3 is very high, however Fertilizer Institute surveys suggest that the energy use for $P_2O_5$ production dropped in half from the 1979 to the 1983 survey (as cited in reference 4) suggesting that modern production processes would be in line with other estimates. Lacking a better method I will use the value cited in reference 8, from the Fertilizer Institute, and assume that this is the best representation of average U.S. practices.

Energy Requirements for Fertilizer Production (Btu/lb nutrient) — Fraction of Fuels

| | Natural Gas | Electricity (Kw | Oil | Total Fuel | Total (kwh at | Natural Gas | Fuel Oil |
|---|---|---|---|---|---|---|---|
| Anhydrous A | 21,171 | 0.058 | 0 | 21,171 | 21,747 | 100% | 0% |
| Urea | 26,999 | 0.238 | 0 | 26,999 | 29,381 | 100% | 0% |
| Nitrogen Solu | 23,442 | 0.146 | 0 | 23,442 | 24,902 | 100% | 0% |
| Phosphates | 1,086 | 0.196 | 1,127 | 2,213 | 4,175 | 49% | 51% |
| Potash | 1,156 | 0.091 | 0 | 1,156 | 2,062 | 100% | 0% |

---

Table 8 Energy Use for Fertilizer Packaging and Transportation

(1) Bhat, Mahadev G., Burton C. English, Anthony Turhollow, and Herzron Nyangito. 1993. Energy Use in Synthetic Agricultural Inputs: Revisited, Report prepared by the Department of Agricultural Economics and Rural Sociology, The University of Tennessee, Knoxville, for Biofuels Feedstock Development Program Environmental Sciences Division, Oak Ridge National Laboratory, ORNL/Sub/90-99732/2.

(2) Mudahar, M.S. and T.P. Hignett. 1981. Energy and Fertilizer: Policy Implications and Options for Developing Countries, Executive Brief, Technical Bulletin IFDC-T-19, International Fertilizer Development Center, Muscle Shoals, Alabama.

(3) Mudahar, M.S. and T.P. Hignett. 1982. Energy and Fertilizer: Policy Implications and Options for Developing Countries, Executive Brief, Technical Bulletin IFDC-T-19, International Fertilizer Development Center, Muscle Shoals, Alabama.

Energy Use for Packaging and Transportation

| | Nitrogen | Phosphorous | Potash | Units |
|---|---|---|---|---|
| Packaging | 2.58 | 2.65 | 1.75 | GJ/mt |
| Transportatio | 4.47 | 5.68 | 4.60 | GJ/mt |
| Total | 7.05 | 8.33 | 6.35 | GJ/mt |

| | Nitrogen | Phosphorous | Potash | Units |
|---|---|---|---|---|
| Packaging | 1,108 | 1,138 | 752 | Btu/lb |
| Transportatio | 1,920 | 2,440 | 1,976 | Btu/lb |
| Total | 3,029 | 3,579 | 2,728 | Btu/lb |

Notes: This data is used by reference 1 to estimate packaging and transportation energy use for fertilizers. Reveiwing the source, however, this data was generated with particular reference to international applications, and thus may not be representative of U.S. average practices, especially for transportation. By comparison, the energy needed to make packaging material is quite small (see below). Also, most fertilizer is shipped in bulk in the U.S. (also below). Anhydrous ammonia, which is the most important form of nitrogen use for corn in Iowa, is also the least energy intensive to transport (pipeline). Thus it will be assumed that the energy use to package fertilizers for corn use is negligible. Transportation energy use estimates are included in the estimates of direct energy use on the farm, and are derived from Shapouri et al 1995.

Energy Use for 50 Kg Polyethylene Plastic Fertilizer Bags (3)

420 MJ/metric ton    180 Btu/lb

Consumption of Fertilizer by Class in the U.S. 1992

| | Short tons | |
|---|---|---|
| Dry Bulk Sing | 12,313,103 | 94% of single nutrient is bulk |
| Dry Bagged S | 742,949 | 6% |
| Total Dry Sin | 13,056,052 | |
| Dry Bulk Mul | 10,949,818 | 78% of multinutrient is bulk |
| Dry Bagged M | 3,126,493 | 22% |
| Total Dry Mu | 14,076,310 | |
| Total Fluid | 18,085,682 | 40% of total is liquid |
| Total | 45,218,045 | |

---

Table 9 Energy Use in the Production of Herbicides and Insecticides


(1) Bhat, Mahadev G., Burton C. English, Anthony Turhollow, and Herzron Nyangito. 1994. Energy Use in Synthetic Agricultural Inputs: Revisited, Report prepared by the Department of Agricultural Economics and Rural Sociology, The University of Tennessee, Knoxville, for Biofuels Feedstock Development Program Environmental Sciences Division, Oak Ridge National Laboratory, ORNL/Sub/90-99732/2.

(2) Pimentel, David et al. 1988. Food Versus Biomass Fuel: Socioeconomic and Environmental Impacts in the United States, Brazil, India, and Kenya, Advances in Food Research, Vol. 32, pp. 185-238, 1988.

(3) Weinblatt, Herbert, T.S. Reddy, and Anthonly Turhollow. 1982. Energy and Precious Fuels Requirements of Fuel Alcohol Production, Vol. II, Appendices A and B: Ethanol from Grain, DOE/NASA/0292-1

(4) Green, M.B. 1987. Energy in Pesticide Manufacture, Distribution and Use, in Energy in World Agriculture, Energy in Plant Nutrition and Pest Control, Volume 2, Z.R. Helsel (ed.), Elsevier Press, New York.


Energy Intensity of Pesticide Production (per unit a.i) (4 and 1)

| Herbicide | Energy Intensity (GJ/ton | Energy Inten | Use Rate (lb/bu) | Energy Int. x Use Rate |
|---|---|---|---|---|
| 2,4-D | 85 | 36,516 | 4.01E-04 | 14.63 |
| Alachlor | 278 | 119,428 | 4.01E-03 | 478.89 |
| Atrazine | 190 | 81,623 | 6.24E-03 | 509.42 |
| Bentazon | 434 | 186,445 | 6.55E-05 | 12.21 |
| Bromoxynil | 150 | 64,440 | 1.72E-04 | 11.09 |
| Butylate | 141 | 60,573 | 7.34E-04 | 44.47 |
| Chlorsulfuron | 365 | 156,803 | | 0.00 |
| Cyanazine | 201 | 86,349 | 3.23E-03 | 278.86 |
| Dicamba | 295 | 126,731 | 6.10E-04 | 77.26 |
| Diuron | 270 | 115,991 | | 0.00 |
| EPTC | 160 | 68,736 | 1.30E-03 | 89.03 |
| Fluazifop-me | 518 | 222,531 | | 0.00 |
| Glyphosate | 454 | 195,037 | 1.78E-04 | 34.69 |
| Isopropalin | 150 | 64,440 | | 0.00 |
| Linuron | 290 | 124,583 | 5.60E-06 | 0.70 |
| MCPA | 130 | 55,848 | | 0.00 |
| Methazole | 150 | 64,440 | | 0.00 |
| Metolachlor | 276 | 118,569 | 4.91E-03 | 581.76 |
| Metribuzin | 200 | 85,919 | | 0.00 |
| Molinate | 150 | 64,440 | | 0.00 |
| Norflurazon | 150 | 64,440 | | 0.00 |
| Pendimethali | 150 | 64,440 | 3.22E-04 | 20.74 |
| Prometryn | 200 | 85,919 | | 0.00 |
| Propanil | 220 | 94,511 | | 0.00 |
| Trifluralin | 150 | 64,440 | 6.95E-06 | 0.45 |
| Propachlor | 290 | 124,583 | 1.67E-04 | 20.78 |

| | | | | |
|---|---|---|---|---|
| Paraquat | 460 | 197,615 | 5.15E-05 | 10.18 |
| | | | 0.02 | 2185.16 |
| | | Wt. average Energy Intensity | | 97,575 |

Notes: Reference 1 cites reference 4 data, then uses the data to extrapolate to pesticides not covered by reference 4. Reference 1 incorrectly cites the energy intensity of diuron at 200 GJ/mt, instead of 270 GJ/mt from the original reference. The other values are correct. Use rates are from Table 2 of this sheet.

Energy Intensity of Insecticide Production (1 and 4)

| Insecticide | Energy Intensity (GJ/tor | Energy Inten | Use Rate (lb/bu) | Energy In. x Use Rate |
|---|---|---|---|---|
| Chlorpyrifos | 250 | 107,399 | 7.34E-04 | 78.78 |
| Fonofos | 200 | 85,919 | 2.57E-04 | 22.11 |
| Fensulfothion | 200 | 85,919 | | 0.00 |
| Terbufos | 200 | 85,919 | 6.81E-04 | 58.55 |
| Carbofuran | 454 | 195,037 | 1.63E-04 | 31.85 |
| Methyl parath | 160 | 68,736 | 8.53E-05 | 5.86 |
| Phorate | 209 | 89,786 | 1.44E-04 | 12.90 |
| | | | 2.06E-03 | 2.10E+02 |
| Wt. Average | | | | 101,742 |

Other estimates of Energy Use in Pesticide Production

| | | | | | | |
|---|---|---|---|---|---|---|
| Insecticide | | 100,000 | kcal/kg | (2) | 179,999 | Btu/lb |
| Herbicide | | 100,000 | kcal/kg | (2) | 179,999 | Btu/lb |
| Pesticides | Wisconsin | 231,000 | Btu/acre | (3) | 2,265 | Btu/bu |
| | Nebraska | 228,000 | Btu/acre | (3) | 2,092 | Btu/bu |
| | Kansas | 245,000 | Btu/acre | (3) | 2,333 | Btu/bu |

---

Table 10 Energy Use in Pesticide Formulation and Packaging

(1) Pimentel, David (ed.). 1980. Handbook of Energy Utilization in Agriculture, CRC Press, Boca Raton, FL.

(2) Green, M. 1987. Energy in Pesticide Manufacture, Distribution, and Use, Energy in Plant Nutrition and Pest Control, ed. Z.R. Helsel, New York, Elsevier, pp. 165-196.

Pesticide Formulation and Packaging
Energy Use

| | | Raw Input/ Quantity | Raw/ Input Units | Source | Transformed Input Quan. | Transformed Input Units | Notes: | Fuel Types (%) Oil | Gas | Coal |
|---|---|---|---|---|---|---|---|---|---|---|
| Herbicides | Miscible Oil | 41,800 | kcal/kg | (1) | 75,240 | Btu/lb | | 60% | 23% | 17% |
| | Wettable Powder | 5,100 | kcal/kg | (1) | 9,180 | Btu/lb | | 43% | 37% | 20% |
| | Granules | 23,600 | kcal/kg | (1) | 42,480 | Btu/lb | | 42% | 37% | 21% |
| | Average | 23,500 | kcal/kg | | 42,300 | Btu/lb | | 48% | 32% | 19% |
| Insecticides | Miscible Oil | 41,800 | kcal/kg | (1) | 75,240 | Btu/lb | | 61% | 23% | 16% |
| | Wettable Powder | 5,100 | kcal/kg | (1) | 9,180 | Btu/lb | | 43% | 37% | 20% |
| | Granules | 23,600 | kcal/kg | (1) | 42,480 | Btu/lb | | 42% | 37% | 21% |
| | Dust | 23,600 | kcal/kg | (1) | 42,480 | Btu/lb | | 42% | 37% | 21% |
| | Average | 23,525 | kcal/kg | | 42,345 | Btu/lb | | 47% | 34% | 20% |

| | | | | | |
|---|---|---|---|---|---|
| Pesticides | Miscible Oil | 22 GJ/mt | (2) | 9,451 | Btu/lb |
| | Wettable Powder | 32 GJ/mt | (2) | 13,747 | Btu/lb |
| | Granules | 12 GJ/mt | (2) | 5,155 | Btu/lb |
| | Average | 22 GJ/mt | (2) | 9,451 | Btu/lb |

Notes: There is extremely wide variation in pesticide energy intensity estimates. Though pesticide use in corn farming is small on a mass basis, because pesticides are very energy intensive, the overall impact on corn energy use is not insignificant. Lacking a better reason, reference 2 will be used because it is more recent.

---

Table 11 Energy Use in Seed Production


(1) Shapouri, H, J.A. Duffield, and M.S. Graboski. 1995. Estimating the Net Energy Balance of Corn Ethanol, USDA/ERS, Economic Report Number 721, Washington, D.C.

(2) Pimentel, David (ed.). 1980. Handbook of Energy Utilization in Agriculture, CRC Press, Boca Raton, FL.

(3) Giampietro, M., and David Pimentel. 1990. Alcohol and Biogass Production from Biomass, Critical Reviews in Plant Sciences; Vol. 9, No. 3, pp. 213-233.

(4) Economic Report to the President. 1995. Transmitted to the Congress February 1995, U.S. GPO, Washington, D.C.

(5) United States Department of Energy, Energy Information Administration. 1993. Annual Energy Review: 1993, DOE/EIA-0384(93).

(6) Personal Communication with David Bruch, Gro-Mart Seed Division, Bloomington, IL, Sept. 20, 1995.


| | | |
|---|---|---|
| Seeding Rate | 0.12 | lb/bu |
| | 0.0021 | lb seed/lb corn |

| Raw/ Input Quan. | Raw/ Input Units | Source | Transformed Input Quan. | Transformed Input Units | Notes: |
|---|---|---|---|---|---|
| 186 | Btu/Bu | (1) | 186 | Btu/bu | 9-State Average |
| 24,806 | Kcal/kg seed | (2) | 5,285 | Btu/bu | U.S. Average |

Notes: Sources (2) and (3) rely on estimates of the energy intensity to propagate crops based on the relative cost of feed corn versus hybrid seed corn. Using 1977 data on the retail cost of corn seed ($0.71/lb) and 1973 energy use per $GNP ( 15,800 kcal/$), the energy cost is computed at 24,806 kcal/kg. This is the approximate figure which is used in both the referenced sources. Reference 1 is based on the assumption that seed requires 150% of the energy that is required for grain. Neither method is particularly appealing. One relies on very gross assumptions about the relationship of costs and energy consumption in the hybrid corn seed industry, the other is just a guess. Lacking other options, it is at least possible to update the estimates based on energy use per unit gross domestic product. This data is presented below.

| Year | Domestic Energy Consu (Quads) | Gross Dome (Billion $) | Ratio Btu/$ GDP | Ratio (Kcal/$ GDP) | Seed Cost ($/80,000 Kernals) | Kernals/lb | Seed Cost ($/ lb) | Energy Intensity (Btu/lb seed) | Energy Intensity (Btu/bu corn) |
|---|---|---|---|---|---|---|---|---|---|
| 1991 | 81.12 | 5724.8 | 14,170 | 3,571 | 70.2 | 1300 | 1.14 | 16,164 | 1,913 |
| 1992 | 82.14 | 6020.2 | 13,644 | 3,439 | 71.8 | 1300 | 1.17 | 15,919 | 1,884 |
| 1993 | 83.96 | 6343.3 | 13,236 | 3,336 | 72.7 | 1300 | 1.18 | 15,637 | 1,851 |
| Average | | | 13,683 | | | | | | 1,883 |

Notes: Accordingly, the current estimate of energy use to produce corn seed is much smaller than the estimate made based on 1970's data. This is due both to a more energy efficient economy (i.e. lower btu/$ GDP) and due to lower seed prices (current prices are equivalent to about $0.45/lb in 1977 dollars). Interestingly, my estimate of the energy intensity of the U.S. economy in 1973 is also about 12% less than the estimate made in reference 2. Combined, current energy intensity estimates are only about 40% of those made based on the 1970's data. The veracity of the gross argument made is also still in question. As a rough check, however, it is interesting to estimate the energy intensity of corn production based on the same method. Ass 34,208 Btu/bu. This is 63.41% of the estimate made in this report. Thus the seed energy intensity estimate can be considered a valid, but crude, estimate.

As a check, a rough direct estimate can be made of the energy use to grow seed. David Bruch cited some 1994 production numbers of 47 units net production per acre, and planting rates of about 27,000 plants per acre. This works out to 3 acres seeded per unit, or:

| | |
|---|---|
| 47 | units seed/acre seed |
| 3 | acres grain/unit seed |
| 141 | acres grain/acre seed |

| | | |
|---|---|---|
| Energy use p | 6,503,299 | Btu/acre corn |

| | | |
|---|---|---|
| Assuming equivalent energy use per acre seed, energy use per acre grain for seed is: | 46,123 | Btu/acre corn |
| or: | 383 | Btu/bu corn |

This is already double the estimate in reference 1, and does not include any additional energy for seed processing. There are many aspects of seed production which are markedly more energy intensive than grain. For example, seed corn is planted in two passes, one for each of the parents. An additional tractor pass is made to burn back one or two rows to ensure proper pollination. This year, for example, some fields were sprayed up to 4 times from corn borer. Seed corn is also mechanically detassled. In some cases pesticide use is very much higher. Probably the most significant area of additional energy use, however, is in drying and storage. Seed corn is harvested wet (35% moisture) and dried on the ear down to 12% moisture. Using data from Table 17 an estimate of drying energy use can be made:

| | | |
|---|---|---|
| Harvested moisture of c | 35% | |
| Stored moisture of corn | 12% | |
| Harvested water weight | 26.54 | lb/bu |
| Stored water weight | 6.72 | lb/bu |
| Stored corn weight | 49.28 | lb/bu |
| Water to be evaporated | 19.82 | lb/bu |
| Gross Energy to Dry Se | 35,691 | btu/bu seed |
| Gross Energy to Dry Se | 637 | btu/lb seed |
| Energy per unit corn pro | 75.43 | btu/bu corn |

This does not include the water in the cob itself, so energy use for drying would be even higher. Clearly Different practices in the seed industry lead to dramatically higher energy costs. The calculation below is a rough estimate of incremental additions in energy use on the farm for hybrid seed production. Included are estimates of triple the farm machinery use, 20% additional energy for drying due to water in the cob, and double the energy use for pesticides.

| Item | Energy use per Acre | Estimated Mu | Energy Use per A | Energy Use p | Energy Use per Bu corn |
|---|---|---|---|---|---|
| Nitrogen | 2,876,833 | 1 | 2,876,833 | 55,700 | 118 |
| Potash | 115,234 | 1 | 115,234 | 2,231 | 5 |
| Phosphate | 197,113 | 1 | 197,113 | 3,816 | 8 |
| Lime | 90,198 | 1 | 90,198 | 1,746 | 4 |
| Chemicals | 325,118 | 2 | 650,236 | 12,590 | 27 |
| Drying | 1,606,101 | 1.2 | 1,927,322 | 37,316 | 79 |
| Farm Vehicle | 1,644,030 | 3 | 4,932,089 | 95,494 | 202 |
| Total | 6,854,628 | | 10,789,026 | 208,894 | 442 |

Notes: Assumes 80,000 kernals/unit and 1,300 kernals/lb. Some additional energy is used for airconditioned storage of seed, packaging, and transportation, but it seems unlikely that this would increase the total as high as the value estimated from btu/$ GDP. The actual value is probably between 600 and 1800 btu/bu corn. Lacking more detailed data on corn seed production practices, however, the estimate based on btu/$ will be used.

---

Table 12 Energy Use in Lime and Sulfur Production

(1) Hudson, Charles L. 1982. Energy Requirements for Materials Used in Vehicles Characterized for the Tapcut Project, Argonne National Laboratory, ANL/EES-TM-211.

(2) Pimentel, David (ed.). 1980. Handbook of Energy Utilization in Agriculture, CRC Press, Boca Raton, FL.

(3) Giampietro, M., and David Pimentel. 1990. Alcohol and Biogass Production from Biomass, Critical Reviews in Plant Sciences, Vol. 9, No. 3, pp. 213-233.

(4) Blankenhorn, Paul R., et al. 1986. Net Financial and Energy Analyses for Producing Populus Hybrid Under Four Management Strategies: First Rotation, Oak Ridge Nat'l Laboratory, ORNL/Sub/79-07928/1.

(5) Mudahar, M.S. and T.P. Hignett. 1982. Energy and Fertilizer: Policy Implications and Options for Developing Countries, Executive Brief, Technical Bulletin IFDC-T-19, International Fertilizer Development Center, Muscle Shoals, Alabama.

(6) U.S. Department of the Interior, Bureau of Mines. 1994. Mineral Commodity Summaries: 1994

Energy Use in Lime and Sulfur Production

| | | | | |
|---|---|---|---|---|
| Lime | 316 kcal/kg | (3) | 569 Btu/lb | |
| | 566 Btu/lb | (4) | 566 Btu/lb | |
| | 315.45 kcal/kg | (2) | 568 Btu/lb | This source explicitly states that 300 kcal/kg is transport. |
| | | Average | 568 Btu/lb | |
| | | St. Dev. | 1 Btu/lb | |

Notes: I suspect that all three of these sources are relying on the 1980 estimate by Pimentel of the energy use to produce limestone. Pimentel's estimates suggest that almost all of the energy use is for transport of the limestone, while mining costs are very small. He cites no data source for the transportation estimate, however, making the total value somewhat questionable. Apparently this single value has progagated through the literature for some time. There is no apparent source of better data. The mining part of the energy consumption estimate is based on 1972 Census of Mineral Industries data.

| | GJ/mt | | |
|---|---|---|---|
| Sulfur | 7.38 | 9,511 Btu/lb | (5) |
| Percent of Su | 21% | 1997 Btu/lb | (6) |

Notes: About 15% of domestic sulfur use in the U.S. is domestically produced, Frasch Process sulfur. Domestically produced recovered sulfur accouts for 55%. Since sulfur recovery is often carried out in the purification of fuel feedstocks, or for pollution control purposes, it is unclear whether energy use in these processes should be counted towards sulfur production. Hudson (1 ) cites an energy intensity of sulfur production of 443 Btu/lb.

---

Table 13 Fertilizer Type Mix in Iowa (a state heavily devoted to corn production)

(1) Tennessee Valley Authority, Commercial Fertilizers: 1994, TVA Environmental Research Center, TVA, Muscle Shoals, Alabama.

(2) The Fertilizer Institute. 1982. The Fertilizer Handbook

Iowa Fertilizer Consumption :1994 (1)

| | | Raw Input Quanitity | Units | Notes: | Percent | |
|---|---|---|---|---|---|---|
| Nitrogen | Multi Nutrient Grade | 103186 | short tons N | p. 17 | | |
| | Single Nutrient Grade | 932724 | short tons N | p. 17 | | |
| | Total N | 1035910 | short tons N | p. 17 | | |
| Phosphates | Multi Nutrient Grade | 284130 | short tons P2O5 | p. 17 | | |
| | Single Nutrient Grade | 9844 | short tons P2O5 | p. 17 | | |
| | Total P2O5 | 293974 | short tons P2O5 | p. 17 | | |
| Potassium | Multi Nutrient Grade | 38507 | short tons K2O | p. 17 | | |
| | Single Nutrient Grade | 403517 | short tons K2O | p. 17 | | |
| | Total K2O | 442024 | short tons K2O | p. 17 | | |
| Single Nutrie | Anhydrous Ammonia | 597445 | short tons N | p. 20 | 65.08% | |
| | Nitrogen Solutions | 235127 | short tons N | p. 20 | 25.61% | |
| | Urea | 85472 | short tons N | p. 20 | 9.31% | |
| | Total Single | 918044 | short tons N | | 98.43% | Of total single nutrient N |
| Multiple Nutr DAP | | 378850 | short tons DAP | p. 15 | | |

| | | | | | |
|---|---|---|---|---|---|
| | | 68193 | short tons N | p. 15 | 66.09% Of total multi nutrient N |
| | | 174271 | short tons P2O5 | p. 15 | 59.28% Of total P2O5 |
| Potassium | Potassium Chloride | 400,923 | short tons K2O | p. 21 | 90.70% Of total K2O |

Notes: Fertilizer use in Iowa is weighted towards single nutrient types except for phosphates, for which DAP is the most common type used.
In order to simplify the evaluation of energy and emissions associated with fertilizer manufacture, nitrogen energy intensity will be estimated from the weighted average of the single nutrient nitrogen sources, and phosphate energy intensity will be taken from a generic value for phosphate fertilizers. Emissions estimates will then be derived from the quantity of raw materials and intermediates used to manufacture the fertilizers.

Physical and Chemical Characteristics of Nitrogen Solution (2)
(28% N in solution)

| | |
|---|---|
| Urea N: Amm | 1.04 (unitless) |
| Urea N | 50.98% |
| Ammonium N | 49.02% |

Table 14 Corn Production Energy Use for Fertilizer

Fertilizer Energy Intensity in Corn Production

| | | Quantity (lb/bu) | Fuel Energy Inter (Btu/lb) | El. Energy In (kwh/lb) | Fuel Energy Intens (Btu/bu) | Electric Energy Inten (kwh/bu) | Notes: | N.G | Fuel Oil | Electricity | Total Fuel | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Calculated | N | 1.03 | 22,295 | 0.097 | 22,871 | 0.100 | Fraction of Fertilizer type and fraction of makeup of nitrogen solution from T | 22,871 | 0 | 0.100 | | 23,866 |
| | P | 0.39 | 2,213 | 0.196 | 867 | 0.077 | Average of fertilizer types | 425 | 442 | 0.077 | | 1,635 |
| | K | 0.46 | 1,156 | 0.091 | 536 | 0.042 | Average value | 536 | 0 | 0.042 | | 956 |
| | Total | 1.88 | 25,663 | 0.384 | 24,273 | 0.722 | | 23,831 | 442 | 0.218 | 24,273 | 26,458 |

Notes: Energy use from fertilizer consumption is calculated from the quantity of fertilizer used (Table 2), the energy intensity of fertilizer production (Table 7), and, for nitrogen, some information about the mix of nitrogen fertilizer types used in Iowa (Table 13). Fuel mix information is also in Table 7.

Table 15 Direct Energy Use in Corn Production

(1) Shapouri, H, J.A. Duffield, and M.S. Graboski. 1995. Estimating the Net Energy Balance of Corn Ethanol, USDA/ERS, Economic Report Number 721, Washington, D.C.

(2) Ali, Mir, and W. McBride. 1994. Corn: State-Level Production Costs, Characteristics, and Input Use, 1991, USDA/ERS, SB-891.

Fuel Use by State (1)

| | Units | Illinois | Indiana | Iowa | Michigan | Minnesota | Nebraska | Ohio | South Dakota | Wisconsin | Weighted Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Diesel | Btu/bu | 4793 | 5843 | 4686 | 8620 | 5427 | 18881 | 5131 | 10650 | 9184 | 7713 |
| Gasoline | Btu/bu | 3439 | 3710 | 3281 | 3530 | 3019 | 4301 | 2723 | 4846 | 2802 | 3493 |
| LP Gas | Btu/bu | 1515 | 1619 | 3292 | 2654 | 3287 | 2510 | 2780 | 5705 | 1578 | 2575 |
| Natural Gas | Btu/bu | 479 | 85 | 0 | 464 | 0 | 12632 | 85 | 0 | 90 | 2058 |
| Electricity (2) | kwh/bu | 0.097 | 0.235 | 0.041 | 0.097 | 0.233 | 0.744 | 0.081 | 1.094 | 0.605 | 0.276 |
| Custom Work | Btu/bu | 1480 | 1213 | 1289 | 927 | 1131 | 1106 | 981 | 1271 | 3619 | 1371 |
| Custom Dryin | Btu/bu | 902 | 1153 | 1463 | 1654 | 1321 | 1153 | 764 | 39 | 964 | 1134 |
| Input Hauling | Btu/bu | 1062 | 1062 | 1062 | 1062 | 1062 | 1062 | 1062 | 1062 | 1062 | 1062 |

Total

| | | |
|---|---|---|
| Diesel | Btu/bu | 10,146 |
| Gasoline | Btu/bu | 3,493 |

| | | |
|---|---|---|
| LP Gas | Btu/bu | 3,210 |
| Natural Gas | Btu/bu | 2,557 |
| Electricity (2) | Kwh/bu | 0.276 |
| Total | | 19,406 |

Notes: Electricity use per bushel has been converted back to Kwh using the conversion factor given in reference 1 (12,456 btu/kwh). This value can be checked in reference 2, and is correct. Following the convention in reference 1, energy use for custom work and input hauling has been allocated to the diesel category. Energy use in custom drying is allocated to the LPG and natural gas categories according the the relative importance of these two fuels (44% N.G.: 56% LPG).

---

Table 16 Dryer Type Specific Energy Intensity Estimates

(1) Personal Communication with Dr. Charles Hurburgh, Iowa State University, July 24, 1995.

(2) Personal Communication with Dr. Fred Bakker-Arkema, Michigan State University, Department of Ag. Engineering, July 27, 1995.

(3) Personal Communication with Bill Wilcke, University of Minnesota, Department of Ag. Engineering, July 25, 1995

(4) Iowa Agricultural Statistics. 1991. Iowa Crop Report, press release of March 5, 1991, Iowa Agricultural Statistics, Des Moines, Iowa.

Corn Drying Energy Consumption Estimates

| Dryer Type | Energy | Units | Source | Notes: |
|---|---|---|---|---|
| Low Temp. | 1,400 | Btu/lb water | (1) | He gave these as the range of possible values, in |
| High Temp. | 3,000 | Btu/lb water | (1) | which most dryers should fall. |
| Ambient Air-L | 1,450 | Btu/lb water | (2) | Range: 1,200 to 1,600 |
| High Temp. B | 1,950 | Btu/lb water | (2) | Range: 1,500 to 2,400 |
| Continuous High Temp. | | | | |
| Cross Flow | 2,050 | Btu/lb water | (2) | Range: 1,700 to 2,400 |
| Mixed Flow | 1,800 | Btu/lb water | (2) | Range: 1,600 to 2,000 |
| Concurrent F | 1,650 | Btu/lb water | (2) | Range: 1,500 to 1,800 |
| Average | 1,833 | Btu/lb water | | |
| Bin Batch | 1,500 | Btu/lb water | (3) | |
| Column Batc | 2,100 | Btu/lb water | (3) | |
| Continuous F | 2,650 | Btu/lb water | (3) | Range: 2,100 to 3,200 |
| Natural w/ele | 1 | kwh/bu | (3) | From 22 to 15% moisture |
| | 870 | Btu/lb water | | |

Percent of Corn Dried By Type: Iowa 1990 (4)

| | | Energy Inten | Product |
|---|---|---|---|
| Column Type | 9.1% | 2,100 | 191 |
| Column Type | 13.6% | 1,833 | 249 |
| Batch-in-Bin | 21.4% | 1,500 | 321 |
| Continuous-f | 17.5% | 2,650 | 464 |
| Bin Dryer wit | 35.9% | 1,500 | 539 |
| Other | 2.5% | 1,500 | 38 |

Mid-Range Energy Intensity Estimate
1,801 Btu/lb water

---

Table 17 Net Corn Drying Energy Intensity

(1) Iowa Agricultural Statistics. 1991. Iowa Crop Report, press release of March 5, 1991, Iowa Agricultural Statistics, Des Moines, Iowa.

(2) Hill, L.D., J.P. Brophy, S. Zhang, and W. Florkowski. 1991. Farmer Attitudes Towards Technological Changes Affecting Grain Handling and Quality, Bulletin 805, University of Illinois at Urbana-Champaign, College of Agriculture, Agricultural Experiment Station.

(3) CE Power Systems. 1967. Steam Tables: Properties of Saturated and Superheated Steam, reprinted from ASME Steam Tables (1967).

(4) Cengel, Y. A., and M. Boles. 1989. Thermodynamics: An Engineering Approach, McGraw-Hill, Inc., New York.

(5) Personal communication with Bill Wilcke, University of Minnesota, Department of Agricultural Engineering, July 25, 1995.

(6) Personal communication with Fred Bakker-Arkema, Michigan State University, July 27, 1995.

(7) Shapouri, H, J.A. Duffield, and M.S. Graboski. 1995. Estimating the Net Energy Balance of Corn Ethanol, USDA/ERS, Economic Report Number 721, Washington, D.C.

(8) Ali, Mir, and W. McBride. 1994. Corn: State-Level Production Costs, Characteristics, and Input Use, 1991, USDA/ERS, SB-891.

Source:
Corn Dried by Method: Percent of To(1)

| Year | 1986 | 1988 | 1989 | 1990 | Average |
|---|---|---|---|---|---|
| Natural Dryin | 15.3 | 20.7 | 22.8 | 19 | 19.45 |
| On Farm Arti | 68.1 | 61.5 | 58.1 | 62.1 | 62.45 |
| Off Farm Arti | 16.6 | 17.8 | 19.1 | 18.9 | 18.10% |

Source:
Percent of Cc(2)

Source:
(8)

| | 1971 | 1976 | 1986 | 1991 |
|---|---|---|---|---|
| Illinois | 34 | 42 | 49 | 38 |
| Iowa | 27 | 45 | 53 | 47 |
| Indiana | 36 | 53 | 58 | 31 |
| Average | 32 | 47 | 53 | 39 |

Notes: Information on corn drying varies significantly from source to source. The above information includes some of the available estimates of the fraction of corn dried, and the fraction dried on and off of the farm. Because of conflicting estimates, estimates of fuel use for corn drying were taken directly from reference 7. This are compared below to theoretical values.

| Item | Value | Units | Source | Notes: |
|---|---|---|---|---|
| Specific Heat of Water | 1 | btu/lb-degree Ra | (4) | |
| Enthalpy of vaporization | 970.30 | btu/lb | (3) | At 1 atmosphere |
| Energy to vaporize water from 70 F | 1112.30 | btu/lb | (3) | |
| | | | | |
| Harvested moisture of corn | 23% | | (5) | |
| Stored moisture of corn | 15% | | (5) | |
| Harvested water weight | 14.22 | lb/bu | | |
| Stored water weight | 8.40 | lb/bu | | |
| Stored corn weight | 47.60 | lb/bu | | |
| Water to be evaporated | 5.82 | lb/bu | | |
| | | | | |
| Gross Energy to Dry Corn | 10,480 | lb/bu | | |
| Net Energy to Dry Corn | 5,764 | lb/bu | | |

Notes: Assuming an average of 55% of corn is dried, net energy use values correspond to estimates in reference 7 for corn dried from 23% to 15%, or 8% points. This estimate is not inconsistent with rough estimates

given by Bill Wilcke (10%) and Fred Bakker-Arkema (5% to 12%). Because more accurate data are lacking, it will be assumed that the energy intensity value derived in reference 7 is the most appropriate. Thus all energy use for drying is accounted for in Table 15.

Table 18 Net On-Farm Energy Use

From Table 15

| Energy Use for Corn, 9-State Weight | Raw/ Input Quan. | Raw/ Input Units | Source | Transformed Input Quan. | Transformed Input Units | Notes |
|---|---|---|---|---|---|---|
| Diesel | 10,146 | Btu/bushel | Table 15 | 10,146 | Btu/bu | Based on 9 state average. |
| Gasoline | 3,493 | Btu/bushel | Table 15 | 3,493 | Btu/bu | Based on 9 state average. |
| L.P.G | 3,210 | Btu/bushel | Table 15 | 3,210 | Btu/bu | Based on 9 state average. |
| Natural Gas | 2,557 | Btu/bushel | Table 15 | 2,557 | Btu/bu | Based on 9 state average. |
| Electricity | 3,438 | Btu/bushel | Table 15 | 0.276 | Kwh/bu | Based on 9 state average. |
| Total | 22,166 | Btu/bushel | | | | |

Table 19 Energy Use for Fertilizer in Corn Production

Calculated Values from the last rows of Table 14

| Energy Use for Fertilizer Production | Raw/Input Quantity | Units | Source | DQI | Notes: |
|---|---|---|---|---|---|
| Electricity | 0.218 | Kwh/bushel | Table 14 | 7 | |
| Fuel Oil | 442 | Btu/bushel | Table 14 | 7 | |
| N.G. | 23,831 | Btu/bushel | Table 14 | 7 | |
| Total | 26,458 | Btu/bushel | Table 14 | 7 | |

Table 20 Energy Use for Pesticide Use in Corn Production

From Tables 9 and 10.

| Pesticide Pro Units | Quantity (lb/bu) | Energy Inten (Btu/lb) | Energy Use (Btu/bu) | Oil (Btu) | Gas (Btu) | Coal (Btu) |
|---|---|---|---|---|---|---|
| Herbicides | 0.023 | 97,575 | 2,234 | 1,080 | 722 | 432 |
| Insecticides | 0.0022 | 101,742 | 225 | 106 | 76 | 44 |
| Pesticide For and Packagin | Quantity (lb/bu) | | | | | |
| Herbicides | 0.023 | 9,451 | 216 | 105 | 70 | 42 |
| Insecticides | 0.0022 | 9,451 | 21 | 10 | 7 | 4 |

Total Pesticide Energy Use

| | | |
|---|---|---|
| Oil | 1,300 | Btu/bu |
| N.G. | 875 | Btu/bu |
| Coal | 522 | Btu/bu |
| Total | 2,697 | Btu/bu |

Notes: Energy intensity for production from Table 9, reference 1. Energy intensity for formulation and packaging from Table 10, reference 2.
Fuel mix for total energy use from Table 10, reference 1.

---

Table 21 Energy Use for Seed in Corn Production

(1) Shapouri, H, J.A. Duffield, and M.S. Graboski. 1995. Estimating the Net Energy Balance of Corn Ethanol, USDA/ERS, Economic Report Number 721, Washington, D.C.

| Fuel | % fuel | Energy | Units |
|---|---|---|---|
| Gasoline | 6.80% | 128 | Btu/bu |
| N.G. | 59.90% | 1,128 | Btu/bu |
| Diesel | 26.50% | 499 | Btu/bu |
| Oil | 6.80% | 128 | Btu/bu |
| Seed Produc | 100.00% | 1,883 | Btu/bu |

Notes: Energy type splits from reference 1, in percent, applied to total energy for seed production from Table 11.

---

Table 22 Energy Use for Lime and Sulfur in Corn Production

From Table 6

| | | |
|---|---|---|
| Lime | 728 | btu/bu |
| Sulfur | 20.39 | btu/bu |
| Total | 748 | btu/bu |
| | | |
| Energy Split | | |
| Diesel | 748 | btu/bu |

Note: Reference (1) gives an energy type distribution for lime that includes mostly natural gas and coal. Reference (2) suggests that 95% of fuel use in limestone production is for transportation. Since reference (2) is more explicit about the processes uses, it is assumed that 300 kcal/kg of energy use is for truck haulage, and that diesel trucks are used for this haulage. The remaining energy consumption, and the consumption of energy for sulfur, are lumped into the diesel category because they are small contributions, and there is little data about the mix of fuels for these categories.

---

Table 23 Total Energy Use in Corn Production

| Sum of Previ | Total | Units | Table 12 Pesticide Produc | Table 13 Direct Use | Table 14 Fertilizer Prod | Table 15 Seed Produc | Table 16 Limestone/Sulfur |
|---|---|---|---|---|---|---|---|
| N.G. | 28,391 | Btu/bushel | 875 | 2,557 | 23,831 | 1,128 | 0 |
| Diesel | 11,393 | Btu/bushel | 0 | 10,146 | 0 | 499 | 748 |
| LPG | 3,210 | Btu/bushel | 0 | 3,210 | 0 | 0 | 0 |
| Coal | 522 | Btu/bushel | 522 | 0 | 0 | 0 | 0 |
| Oil | 1,870 | Btu/bushel | 1,300 | 0 | 442 | 128 | 0 |
| Gasoline | 3,621 | Btu/bushel | 0 | 3,493 | 0 | 128 | 0 |
| Electricity | 0.494 | Kwh/bushel | 0.000 | 0.276 | 0.218 | 0.000 | 0.000 |
| | | | | | | | |
| Total Fuel | 49,007 | Btu/bushel | 2,697 | 19,406 | 24,273 | 1,883 | 748 |
| Total Electric | 0.494 | Kwh/bushel | 0.000 | 0.276 | 0.218 | 0.000 | 0.000 |
| Grand Total | 53,952 | Btu/bushel | 2,697 | 22,166 | 26,458 | 1,883 | 748 |

---

Table 24 Nitrogen Oxide Emissions from Corn Production

(1) Eichner, Melissa. 1990. Nitrous Oxide Emissions from Fertilized Soils: Summary of Available Data, J. of Environmental Quality, 19:272-280(1990)

(2) Anderson, I.C., and J. S. Levine. 1987. Simultaneous Field Measurements of Biogenic Emissions of Nitric Oxide and Nitrous Oxide,

Journal of Geophyical Research, vol. 92, no. D1, pp. 965-976, January, 1987.

(3) DeLuchi, M. 1993. Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity, Argonne National Laboratory, ANL/ESD/TM-22, Vol. 2.

(4) Unnasch, Stefan. 1990. Greenhouse Gas Emission from Ethanol Production and Vehicle Use, Acurex Corp. for the Nat'l Corn Growers Association

(5) Watson, R.T. et al. 1990. Greenhouse Gases and Aerosols, in Intergovernmental Panel on Climate Change, Climate Change: The IPCC Scientific Assessment Report Prepared by Working Group I, J.T. Houghton, et al (ed.), UK, 1990.

LCI Component

| N2O Emissions | | Raw Input Quantity | Units | Source | Tranformed Input Quantity | Units | Notes |
|---|---|---|---|---|---|---|---|
| | | 0.01 | percent | (4) | 1.03E-04 | lb/bu | Refs 4 and 5 probably are citing the same data, though they reference different sources. |
| | | 2 | percent | (4) | 2.05E-02 | lb/bu | |
| | | 0.01 | percent | (5) | 1.03E-04 | lb/bu | Refs 4 and 5 probably are citing the same data, though they reference different sources. |
| | | 2 | percent | (5) | 2.05E-02 | lb/bu | |
| | Anhydrous Ammonium | 2.7 | percent | (1) | 2.77E-02 | lb/bu | Evaluated results of 104 field experiments |
| | Ammonium Nitrate | 0.44 | percent | (1) | 4.51E-03 | lb/bu | |
| | Ammonium Chloride or | 0.25 | percent | (1) | 2.56E-03 | lb/bu | |
| | Urea | 0.11 | percent | (1) | 1.13E-03 | lb/bu | |
| | Calcium Nitrate | 0.07 | percent | (1) | 7.18E-04 | lb/bu | |
| | | 1.2 | percent | (2) | 1.23E-02 | lb/bu | |
| | Corn | 1.5 | percent | (3) | 1.54E-02 | lb/bu | Cites Mosier, A. R. et al. 1986. Soil Losses of Dinitrogen and Nitrous Oxide from Irrigated Crops in Northeastern Colorado, Soil Science Society of America Journal, 50:344-348 |
| | Corn (Anhydrous Ammo | 1.29 | percent | (1) | 1.32E-02 | lb/bu | This data is specific to corn and anhydrous ammonium, so it will be used here. |
| NO Emission | | 0.79 | percent | (2) | 8.10E-03 | lb/bu | |

Notes: NO2 emissions vary by fertilizer type and crop. Reference 1 gives a value for anhydrous ammonia fertilized corn. Since this data most closely represents average practices, and since the value is consistent with other results, it is used in the inventory.

---

Table 25 Pesticide and Nutrient Loss to Surface and Groundwater

(1) Glotfelty, D.E., et al. 1984. Atrazine and Simazine Movement to the Wye River Estuary, Journal of Environmental Quality, 13:115-121

(2) Bowman, B.T., et al. 1994. Tranport of Herbicides and Nutrients in Surface Runoff from Corn Cropland in Southern Ontario Canadian Journal of Soil Science, 7491):59-66, 1994

(3) Buhler, D.D., et al. 1993. Water Quality: Atrazine and Alachlor Losses from Subsurface Tile Drainage of a Clay Loam Soil, Journal of Environmental Quality, 22:583-588, 1993

(4) Battaglin, W.A., D.A. Goolsby, and D.K. Mueller. 1994. Relations Between Use, Concentration, and Transport of Agricultural Chemicals in the Mississippi River Basin, in Proceedings of the Annual Summer Symposium of the American Water Resource Association, Effects of Human Induced Changes on Hydrologic Systems, June 26-29, 1994, Jackson Hole, Wyoming.

(5) Goolsby, D.A., E.M. Thurman, M.L. Pomes, and W.A. Battaglin. 199. Temporal and Geographic Distribution of Herbicides in Precipitation in the Midwest and Northeast United States, 1990-1991, in Proceedings of the Fourth National Conference on Pesticides, New Directions in Pesticide Research, Development and Policy, November 1-3, 1993, Blacksburg, Virginia.

(6) United States Geological Survey. 1993. Selected Papers on Agricultural Chemicals in Water Resources of the Midcontinental United States, U.S.G.S. Open-File Report 93-418, U.S. G.S. , Denver, CO.

(7) The Fertilizer Institute. 1982. The Fertilizer Handbook

Pesticides are transported from the point of application by several methods: surface runoff, leaching, volatilization, and direct airborne dispersal of pesticide which does not reach the target. These pesticides can be detected in surface water, groundwater, and rainwater. References 5 and 6 give information on the prevalance of pesticides in rainwater samples in the midwest. Detection of pesticides and pesticide metabolites is common, and concentrations may reach as high as Federal limits on drinking water concentrations. The total quantity of pesticides found in rainwater is small relative to applications (less than 1%) and does not account for total air emissions of pesticides. It is suggested in these studies that degradation, dry deposition, and drift outside of the study area may account for the remaining air emissions of pesticides. These air emissions have been quantified in Table 42. It should be noted that air emissions of pesticides which appear in rainfall also serve as a pesticide load on surface water.

Pesticides also appear in near surface aquifers. The concentrations found in groundwater are generally much smaller than surface water concentrations. No data has been identified which tracks aquifer loading as a fraction of total pesticide use in a particular region. Because this value is probably small relative to surface water loads, it will be treated as negligible. The data below thus give a gross quantification of pesticide flux to water systems in the midwest.

| LCI Component | | Raw Input Quantity | Units | Source | Notes |
|---|---|---|---|---|---|
| Herbicides | Atrazine | 2.50% | Percent | (1) | Midrange loss of atrazine for years in which significant rainfall occurred within two weeks of application |
| | | 0% | Percent | (2) | |
| | | 6% | Percent | (2) | Up to this level when rain immediately follows application |
| | | 1.53% | Percent | (4) | Annual average based on Mississippi Basin loadings and associated use levels. |
| | Metachlor | 0% | Percent | (2) | Up to this level when rain immediately follows application |
| | | 4% | Percent | (2) | |
| | | 0.79% | Percent | (4) | Annual average based on Mississippi Basin loadings and associated use levels. |
| | Alachlor | 0.22% | Percent | (4) | Annual average based on Mississippi Basin loadings and associated use levels. |
| | Cyanazine | 1.66% | Percent | (4) | Annual average based on Mississippi Basin loadings and associated use levels. |
| | Nitrates | 15.32% | Percent | (4) | Annual average based on Mississippi Basin loadings and associated use levels. |
| | Phosphorous | 1.00% | Percent | (7) | Rough estimate given as less than 1% |
| | Potassium | 3.50% | Percent | (7) | Rough estimate given as midway between N (6%) and P (1%) |
| Subsurface lo | Alachlor | 0.10% | Percent | (3) | Subsurface loss only |
| | Atrazine | 0.10% | Percent | (3) | |

Application rates for insecticides are similar to those for herbicides (generally on the order of 1 lb/acre) but the fraction of acreage treated is much smaller (8% for chlorpyrifos and terbufos compared to 69% for atrazine). This may to some degree explain the lower frequency of detections of insecticides. Reference 6 includes results from samples taken on 8 river systems with the most frequently detected of the top three corn insecticides, fonofos, occurring in a maximum of 34 percent of samples (Illinois River). By comparison virtually all samples from all rivers had detectable quantities of atrazine and metolachlor. Other insecticides, such as diazinon and carbofuran were more prevalent. Because detailed estimates of the fraction of insecticides entering surface water systems have not been made, a rough approximation of 1% will be used.

---

Table 26 PM-10 Fugitive Emissions from Corn Production

(1) AP-42 Compilation of Air Pollutant Emission Factors, 5th Edition Chapter 9.3.2, Grain Harvesting.

(2) U.S. Environmental Protection Agency. 1994. National Air Pollutant Emission Trends, Office of Air Quality, EPA-454/R-94-027.

(3) United States Department of Agriculture, National Agricultural Statistics Service, Crop Production: 1994 Summary, Cr Pr 2-1(95), January 1995.

(4) United States Department of Agriculture. 1994 (revised 1995). Summary Report: 1992 National Resources Inventory, USDA Natural Resources Conservation Service and the Iowa State University Statistical Laboratory.

| Year 1993 Source | Raw Input Quantity 1993 | Raw Input Quantity 1987 | Units | | Notes |
|---|---|---|---|---|---|
| Fugitive PM- (2) from Agricultural Cropland | 6,842 | 7,338 | thousand short tons | | |
| Cultivated No(4) | 325,462 | 350,908 | thousand acres | | As a check on this number, area planted in 1993 can be taken from reference (3). This totals 259,404 thousand acres, but excludes hay production, for which harvested area is given. Adding hay harvested area gives rough estimate of total planted area of 319,029 thousand acres, similar to the NRI value. |
| PM-10 Emiss(calculated) | 0.0210 | 0.0209 | short tons/acre | | |
| PM-10 Emiss(calculated) | 42.045 | 41.823 | lb/acre | | |
| Average value | | 41.93 | lb/acre | 0.348 | lb/bu |

Notes: Reference (2) uses methods described in method (1) to estimate fugitive dust emissions. These can be highly variable dependent on weather conditions. Because reference (4) only gives estimates in 5 year intervals, only two years worth of values can be estimated. Other sources can be used to estimate total cropland, but it is not clear which source of data is most appropriate. The PM-10 emissions are also based on factors only for agricultural tilling. Particulate is also emitted from grain harvesting operations. Reference (1) also gives emission factors for these operations for sorghum. The calculation below shows that these emissions are negligible with respect to the values estimated above. The emission rate is a general factor for cropland, but lacking additional data is used as a surrogate for emissions from corn cropland.

Sorghum Harvesting Emissions (reference 1, Table 9.3.2)

| Item | Value | Units | Value | Units |
|---|---|---|---|---|
| Emission Rate | | | | |
| Harvest Mac | 6.5 | lb/sq mile | 0.01016 | lb/acre |
| Truck Loadin | 0.13 | lb/sq mile | 0.00020 | lb/acre |
| Field Transpo | 1.2 | lb/sq mile | 0.00188 | lb/acre |
| Total | 7.83 | lb/sq mile | 0.01223 | lb/acre |

---

Table 27 Emissions from Energy Consumption in Nitrogenous Fertilizer Manufacture

(1) Energy Information Administration. 1994. Manufacturing Consumption of Energy: 1991, DOE/EIA 0512(91).

(2) United States Environmental Protection Agency. 1995. Compilation of Air Pollutant Emission Factors, AP-42.

(3) United States Department of Energy, Energy Information Administration. 1994. Emissions of Greenhouse Gases in the U.S.: 1987-1992, DOE/EIA-0573.

(4) United States Department of Energy, Energy Information Administration. 1993. Annual Energy Review: 1993, DOE/EIA-0384(93).

| Energy for Nonfuel Purposes (MECS Nitrogenous Fertilizers | Raw Input Quantity | Units | Transformed Input Quantity | Units | Notes: |
|---|---|---|---|---|---|
| Natural Gas | 289 | Tbtu | 52.07% | Feedstock Share | |

| | | |
|---|---|---|
| Total | 290 | Tbtu |

Energy for Heat, Power, etc. (MECS Table A4)

| | | | |
|---|---|---|---|
| Natural Gas | 266 | Tbtu | 47.93% Fuel Share |
| Electricity | 10 | Tbtu | |
| Other | 4 | Tbtu | |

Total Primary Energy Consumption (MECS Table A1)

| | | |
|---|---|---|
| Natural Gas | 555 | Tbtu |
| Electricity | 10 | Tbtu |
| Other | 568 | Tbtu |

Large Industrial Boiler Emission Factors (AP-42, Tables 1.4-1 to 1.4-3)

| | | | | | | |
|---|---|---|---|---|---|---|
| SO2 | | 0.6 | lb/million cubic ft | 0.00058 | lb/million btu | |
| NOx | Uncontrolled | 550 | lb/million cubic ft | 0.53295 | lb/million btu | |
| | Controlled-Lo NOx | 81 | lb/million cubic ft | 0.07849 | lb/million btu | |
| | Controlled-FGR | 53 | lb/million cubic ft | 0.05136 | lb/million btu | |
| | Average Controlled | 67 | lb/million cubic ft | 0.06492 | lb/million btu | |
| | Average | 308.5 | lb/million cubic ft | 0.29893 | lb/million btu | |
| CO | | 40 | lb/million cubic ft | 0.03876 | lb/million btu | |
| PM-10 | | 13.7 | lb/million cubic ft | 0.01328 | lb/million btu | This factor is given as the sum of filterable and condensible particulate. All PM emissions from N.G. consumption are thought to be < 10 microns in diameter |
| Methane | | 0.289 | lb/million cubic ft | 0.00028 | lb/million btu | |
| Non-methane VOC's | | 1.41 | lb/million cubic ft | 0.00137 | lb/million btu | |
| CO2 | | 14.47 | million metric ton | 116.9 | lb/million btu | |
| Heat Content of Natural Gas (AER, T | | 1,032 | Btu/cubic foot | | | |

Emissions from the Use of N.G. in the Manufacture of Fertilizer per Unit Corn Production

| | | |
|---|---|---|
| SO2 | 6.37E-06 | lb/bu |
| NOx | 3.28E-03 | lb/bu |
| CO | 4.25E-04 | lb/bu |
| PM-10 | 1.46E-04 | lb/bu |
| Methane | 3.07E-06 | lb/bu |
| Non-methane VOC's | 1.50E-05 | lb/bu |
| CO2 | 1.28 | lb/bu |

Notes: The share of N.G. used as feedstock for nitrogenous fertilizer manufacture vs. fuel is used to reduce emissions estimates to account for N.G. not consumed in boilers.
Emission factors are converted into units of lb/million btu, which are multiplied by energy consumption and share of energy used as fuel.
Emissions from the consumption of electricity by the industry will be calculated by the electricity module.

N.G. is used as a feedstock through a reforming process to produce hydrogen gas. This is the predominate process for ammonia production in the U.S. The hydrogen is reacted with nitrogen to form ammonia. This process results in the production of carbon dioxide and carbon monoxide. Carbon monoxide can be converted back to carbon dioxide through the water-gas shift reaction. Carbon dioxide has industrial use in several areas including the manufacture of urea from ammonia, but some carbon dioxide is emitted from the process. These and other process related emissions are treated in Table 35.

---

Table 28 Emissions from Diesel Consumption in Limestone Production and Farm Input Hauling


(1) Boynton, Robert S. 1980. Chemistry and Technology of Lime and Limestone, Second Edition, John Wiley and Sons, Inc., New York.

(2) Pimentel, David (ed.). 1980. Handbook of Energy Utilization in Agriculture, CRC Press, Boca Raton, FL.

(3) U.S. Department of the Interior, Bureau of Mines. 1994. Mineral Commodity Summaries: 1994

(4) USDA. 1995.

(5) Blankenhorn, Paul R., et al. 1986. Net Financial and Energy Analyses for Producing Populus Hybrid Under Four Management Strategies: First Rotation, Oak Ridge Nat'l Laboratory, ORNL/Sub/79-07928/1.

(6) United States Department of Energy, Energy Information Administration. 1993. Annual Energy Review: 1993, DOE/EIA-0384(93).

Reference (2) suggests that of 315.45 kcal/kg energy input to limestone production, 300 kcal/kg is for trantportation of the limestone to the user. Reference (4) on the other hand lists fuel type for lime split between natural gas, diesel, and coal, suggesting that transporation is not the major area for energy consumption. Reference (5) also explicitly states that energy use estimates for lime production include energy for mining, production, transporation, storage, and transfer. Because reference (2) is most explicit about energy use, emissions from the production of lime will be estimated based on truck emission factors for diesel trucks. It is also assumed that diesel fuel use by the phosphatic and potassium fertilizer industries is also consumed in trucks.

| Vehicle Capa | Raw Input Quantity | Units | Source | Tranformed Q | Units |
|---|---|---|---|---|---|
| Light Diesel T | 10,000 | lb | BMI Transport Model | | |
| Heavy Diese | 42,000 | lb | BMI Transport Model | | |

| Vehicle Usage Rates | | | | Notes: |
|---|---|---|---|---|
| Light Diesel T | 50.00% | percent | (3) | My guess based on zero data |
| Heavy Diese | 50.00% | percent | (3) | |

| Mileages | | | |
|---|---|---|---|
| Short Haul D | 7.10 | Miles/gallon | BMI Transport Model |
| Long Haul Di | 5.30 | Miles/gallon | BMI Transport Model |

| | | | |
|---|---|---|---|
| Diesel Energ | 5.825 | Million Btu/ba | (6) |

Product of we

Vehicle Registration Mix: January 1 & emissions factors , g/mile

| | Gas Trucks | | | | Light Duty Diesel | | | | Heavy Diesel Trucks | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Model Year | Fraction | Total Hydro. | CO | NOx | Fraction | Total Hydro. | CO | NOx | Fraction | Total Hydro. | CO | NOx | Model Year |
| Model Year - | 0 | 2.8 | 12.6 | 4.4 | 0.008 | 0.3 | 1.2 | 0.9 | 0.031 | 2.4 | 7.9 | 11 | Model Year -1 |
| Model Year - | 0.136 | 2.9 | 13.2 | 4.5 | 0.006 | 0.3 | 1.2 | 0.9 | 0.007 | 2.5 | 8.3 | 11.1 | Model Year - |
| Model Year - | 0.116 | 3.1 | 14.6 | 4.8 | 0.008 | 0.4 | 1.2 | 0.9 | 0.008 | 2.6 | 9.1 | 11.5 | Model Year - |
| Model Year - | 0.099 | 3.2 | 15.6 | 4.9 | 0.011 | 0.4 | 1.3 | 1 | 0.01 | 2.7 | 9.9 | 12 | Model Year - |
| Model Year - | 0.085 | 3.4 | 16.5 | 5.1 | 0.017 | 0.4 | 1.3 | 1 | 0.012 | 2.8 | 10.5 | 12.2 | Model Year - |
| Model Year - | 0.072 | 3.6 | 17.7 | 5.4 | 0.023 | 0.5 | 1.4 | 1 | 0.014 | 2.9 | 11.1 | 12.5 | Model Year - |
| Model Year - | 0.062 | 3.7 | 18.4 | 5.5 | 0.029 | 0.5 | 1.4 | 1.1 | 0.017 | 3 | 11.6 | 12.7 | Model Year - |
| Model Year - | 0.053 | 3.8 | 19.1 | 5.6 | 0.035 | 0.5 | 1.4 | 1.1 | 0.021 | 3.1 | 12.1 | 12.9 | Model Year - |
| Model Year - | 0.045 | 3.9 | 19.7 | 5.7 | 0.041 | 0.5 | 1.5 | 1.1 | 0.025 | 3.2 | 12.5 | 13.1 | Model Year - |
| Model Year - | 0.038 | 4.8 | 41.6 | 5.2 | 0.047 | 0.6 | 1.5 | 1.1 | 0.03 | 3.3 | 13.2 | 17.9 | Model Year - |
| Model Year - | 0.033 | 5.2 | 50.2 | 5.2 | 0.053 | 0.6 | 1.5 | 1.2 | 0.036 | 4 | 13.7 | 18.2 | Model Year - |
| Model Year - | 0.028 | 12.8 | 158.20 | 5.6 | 0.059 | 0.6 | 1.6 | 1.6 | 0.043 | 5.6 | 14.8 | 18.9 | Model Year - |
| Model Year - | 0.024 | 13 | 160.40 | 5.6 | 0.065 | 0.6 | 1.6 | 1.6 | 0.051 | 5.7 | 15.1 | 18.9 | Model Year - |
| Model Year - | 0.02 | 13.1 | 165.20 | 5.7 | 0.071 | 0.6 | 1.6 | 1.7 | 0.061 | 5.8 | 15.4 | 18.9 | Model Year - |
| Model Year - | 0.018 | 13.2 | 167.80 | 5.7 | 0.077 | 0.7 | 1.7 | 1.7 | 0.073 | 6.7 | 16.9 | 20.5 | Model Year - |
| Model Year - | 0.015 | 13.8 | 182.5 | 6.1 | 0.083 | 0.7 | 1.7 | 1.9 | 0.088 | 6.8 | 17.2 | 20.5 | Model Year - |
| Model Year - | 0.013 | 13.9 | 184.80 | 6.1 | 0.089 | 1.4 | 2.4 | 1.9 | 0.105 | 7.3 | 20.2 | 24.8 | Model Year - |
| Model Year - | 0.011 | 18.3 | 211.10 | 6.4 | 0.095 | 1.4 | 2.5 | 2 | 0.126 | 7.4 | 20.5 | 24.8 | Model Year - |
| Model Year - | 0.009 | 19.8 | 241.30 | 7.3 | 0.101 | 1.5 | 2.5 | 2 | 0.151 | 7.5 | 20.7 | 24.8 | Model Year - |
| Model Year - | 0.045 | 19.9 | 243.30 | 7.4 | 0.027 | 1.5 | 2.5 | 2 | 0 | 7.5 | 20.9 | 24.8 | Model Year - |
| Weighted Av | 92.20% | 5.9 | 53.3 | 5.3 | 94.50% | 0.5 | 1.4 | 1.1 | 90.90% | 3.7 | 12.1 | 14.6 | sum |

| Emission Factors | Raw Input Qu | Units |
|---|---|---|

| | | | |
|---|---|---|---|
| Short Haul D | Hydrocarbons | 0.5 | g/mile |
| | Carbon Monoxide | 1.4 | g/mile |
| | NOx | 1.1 | g/mile |
| Long Haul Di | Hydrocarbons | 3.7 | g/mile |
| | Carbon Monoxide | 12.1 | g/mile |
| | NOx | 14.6 | g/mile |
| Emissions | | | |
| | Hydrocarbons | 0.00043 | lb/bu |
| | Carbon Monoxide | 0.00138 | lb/bu |
| | NOx | 0.00161 | lb/bu |
| | CO2 | 0.29174 | lb/bu |

---

Table 29 Emissions from Farm Equipment

(1) U.S. EPA. 1991. Nonroad Engine and Vehicle Emission Study-Report, EPA 460/3-91-02.

(2) U.S. EPA. 1991. Nonroad Engine and Vehicle Emission Study-Appendixes (sp): Draft, 21A-2001 (NTIS #PB92-104462).

(3) United States Department of Energy, Energy Information Administration. 1993. Annual Energy Review: 1993, DOE/EIA-0384(93).

(4) United States Department of Energy, Energy Information Administration. 1994. Emissions of Greenhouse Gases in the U.S.: 1987-1992, DOE/EIA-0573.

| Farm Equipm | Units | Raw Input Quantity | | | | | | Source | Notes |
|---|---|---|---|---|---|---|---|---|---|
| | | HC | CO | NOx | SOx | Particulate | Aldehydes | | |
| Diesel Tracto | lb/1000 gallons | 63.55 | 175 | 438.59 | 31.2 | 45.7 | 12 | (2) | Weighted by factors for large 2WD, small 2WD, and 4WD tractors. |
| Diesel Non-T | lb/1000 gallons | 72.52 | 171 | 435 | 5.28 | 51.3 | 10.2 | (2) | Diesel HC values include exhaust and crankcase emissions. |
| Gasoline Tra | lb/1000 gallons | 178.85 | 4,456 | 213.232 | 5.31 | 8 | 6.8 | (2) | Gasoline HC values include exhaust, crankcase, |
| Gasoline Non | lb/1000 gallons | 192.15 | 4,456 | 213.232 | 5.28 | 6.86 | 4.1 | (2) | and refueling emissions. |

Carbon Dioxide Emission Factors

| | Raw Input Quantity | Units | Source | Transformed | Units | Transformed | Units |
|---|---|---|---|---|---|---|---|
| Diesel | 19.95 | Million mtons | (4) | 43.98 | lb C/million bt | 161.16 | lb CO2/million btu |
| Gasoline | 19.41 | Million mtons | (4) | 42.79 | lb C/million bt | 156.79 | lb CO2/million btu |

| Energy Value | Raw Input Quantity | Units | Source | Transformed | Units |
|---|---|---|---|---|---|
| Diesel | 5.825 | Million Btu/ba | (3) | 138,690 | Btu/gallon |
| Motor Gasoli | 5.253 | Million Btu/ba | (3) | 125,071 | Btu/gallon |

| Direct On-Fa | Raw Input Quantity | Units | Source | Transformed | Units |
|---|---|---|---|---|---|
| Diesel | 9,583 | Btu/bu | Tables 13 and 15 | 0.069 | Gallons/bu |
| Motor Gasoli | 3,621 | Btu/bu | Tables 13 and 15 | 0.029 | Gallons/bu |

| Emissions fro | Quantity | Units |
|---|---|---|
| HC | 9.57E-03 | lb/bu |
| CO | 1.41E-01 | lb/bu |
| NOx | 3.65E-02 | lb/bu |

| | | |
|---|---|---|
| SOx | 2.31E-03 | lb/bu |
| Particulate | 3.74E-03 | lb/bu |
| Aldehydes | 4.70E-04 | lb/bu |
| CO2 | 2.11 | lb/bu |

Notes: Reference (2) lists percentage energy output estimates for diesel equipment. According to that data about 85% of energy use is by tractors. Since non-tractor equipment includes many categories that would not be used on corn farms, such as cotton pickers, orchard sprayers, and mowers, the percentage of energy use for non-tractors on corn farms would be quite small. Also, the difference between tractor and non-tractor emission factors is small. For this reason, emissions estimates are based on the weighted factors for tractors.

Diesel energy use in tractors is taken from Table . Because the total value in this table includes diesel use in input hauling, which is accounted for in a separate table, the individual components for on farm use must be pulled out of the table separately. Diesel use to produce seed is also included in these calculations.

---

Table 30 Emissions from Natural Gas and LPG Use for Corn and Seed Production

(1) U.S. EPA, AP-42, Sections 1.4 and 1.5.

(2) United States Department of Energy, Energy Information Administration. 1994. Emissions of Greenhouse Gases in the U.S.: 1987-1992, DOE/EIA-0573.

Natural gas and LPG are used in corn farming for drying the corn to acceptable moisture content levels for storage, usually 12 to 13%. The EPA publishes particulate emission factors for feed dryers, but does not include emission factors for the products of combustion. In order to estimate emissions from the consumption of natural gas and LPG, factors for uncontrolled commercial boilers will be applied to the direct use of natural gas and LPG on farms, and to the use of natural gas in seed production.

| Emission Factors - Natural Gas | Raw Input | Units | Source | Transformed | IUnits |
|---|---|---|---|---|---|
| NOx | 100 | lb/million cubic fe | (1) | 9.69E-02 | lb/million btu |
| SOx | 0.6 | lb/million cubic fe | (1) | 5.81E-04 | lb/million btu |
| PM-10 | 12 | lb/million cubic fe | (1) | 1.16E-02 | lb/million btu |
| CO | 21 | lb/million cubic fe | (1) | 2.03E-02 | lb/million btu |
| CO2 | 14.47 | million metric ton | (2) | 116.89 | lb/million btu |
| Non-Methane VOC's | 3.83 | lb/million cubic fe | (1) | 3.71E-03 | lb/million btu |
| Methane | 1.97 | lb/million cubic fe | (1) | 1.91E-03 | lb/million btu |

Natural Gas Use In Corn Farming an 3,685 Btu/bu From Tables 13 and 15

Emissions

| | | |
|---|---|---|
| NOx | 3.57E-04 | lb/bu |
| SOx | 2.14E-06 | lb/bu |
| PM-10 | 4.28E-05 | lb/bu |
| CO | 7.50E-05 | lb/bu |
| CO2 | 4.31E-01 | lb/bu |
| Non-Methane VOC's | 1.37E-05 | lb/bu |
| Methane | 7.04E-06 | lb/bu |

| Emission Factors -LPG | Raw Input | Units | Source | Transformed | IUnits |
|---|---|---|---|---|---|
| NOx | 14 | lb/million cubic fe | (1) | 1.36E-02 | lb/million btu |
| SOx | 0.018 | lb/million cubic fe | (1) | 1.74E-05 | lb/million btu |
| Particulate | 0.4 | lb/million cubic fe | (1) | 3.88E-04 | lb/million btu |
| CO | 1.9 | lb/million cubic fe | (1) | 1.84E-03 | lb/million btu |
| CO2 | 17.16 | million metric ton | (2) | 138.62 | lb/million btu |
| Organic Compounds | 3.83 | lb/million cubic fe | (1) | 3.71E-03 | lb/million btu |

| LPG Use In Corn Farming and Seed | 3,210 | Btu/bu | From Tables 13 and 15 |
|---|---|---|---|

Emissions

| | | |
|---|---|---|
| NOx | 4.35E-05 | lb/bu |
| SOx | 5.60E-08 | lb/bu |
| Particulate | 1.24E-06 | lb/bu |
| CO | 5.91E-06 | lb/bu |
| CO2 | 4.45E-01 | lb/bu |
| Organic Compounds | 1.19E-05 | lb/bu |

Total Emissions

| | | |
|---|---|---|
| NOx | 4.01E-04 | lb/bu |
| SOx | 2.20E-06 | lb/bu |
| PM-10 | 4.28E-05 | lb/bu |
| Particulate | 1.24E-06 | lb/bu |
| CO | 8.09E-05 | lb/bu |
| CO2 | 8.76E-01 | lb/bu |
| Non-Methane VOC's | 2.56E-05 | lb/bu |
| Methane | 7.04E-06 | lb/bu |

---

Table 31 Unallocated Emissions from Fuels

(1) United States Department of Energy, Energy Information Administration. 1993. Annual Energy Review: 1993, DOE/EIA-0384(93).

In this table all fuel use for which a specific emission factor could not be found are totalled, and general emission factors used to estimate emissions. This includes fuel use for P and K fertilizer use, fuel use for pesticides and seed use of coal, and oil.

| Sum of Previ | Total | Units | Table 8 | Table 12 | Table 13 | Table 14 Fertilizer Production | | | | Table 15 | Table 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Fertilizer Packag | Pesticide Pro | Direct Use | Nitrogen | Phosphates | Potash | | Seed Product | Limestone/Sulfur |
| N.G. | 1,836 | Btu/bushel | 0 | 875 | (allocated) | (allocated) | 425 | | 536 | (allocated) | 0 |
| Diesel | 0 | Btu/bushel | 0 | 0 | (allocated) | 0 | 0 | | 0 | (allocated) | (allocated) |
| LPG | 0 | Btu/bushel | | 0 | (allocated) | 0 | 0 | | 0 | 0 | 0 |
| Coal | 522 | Btu/bushel | 0 | 522 | 0 | 0 | 0 | | 0 | 0 | 0 |
| Oil | 1,870 | Btu/bushel | 0 | 1,300 | 0 | 0 | 442 | | 0 | 128 | 0 |
| Gasoline | 0 | Btu/bushel | 0 | 0 | (allocated) | 0 | 0 | | 0 | (allocated) | 0 |
| Total Fuel | 4,228 | Btu/bushel | 0 | 2,697 | 0 | 0 | 867 | | 536 | 128 | 0 |

| Emission Fac | N.G. | | Coal | | Oil | |
|---|---|---|---|---|---|---|
| NOx | 140 | lb/million cub | 13.7 | lb/ton | 20 | lb/thousand gallons |
| SOx | 0.60 | lb/million cub | 57 | lb/ton | 143.60 | lb/thousand gallons |
| PM-10 | 14 | lb/million cub | 12.4 | lb/ton | 1 | lb/thousand gallons |
| CO | 35 | lb/million cub | 5 | lb/ton | 5 | lb/thousand gallons |
| CO2 | 14 | Million Mtons | 25.58 | Million Mtons | 19.95 | Million Mtons C/Quad |
| Non-Methane | 2.78 | lb/million cub | 0.05 | lb/ton | 0.34 | lb/thousand gallons |
| Methane | 3.02 | lb/million cub | 0.06 | lb/ton | 0.216 | lb/thousand gallons |
| Particulate | 14 | lb/million cub | 17 | lb/ton | 2 | lb/thousand gallons |

| Energy Value | Quantity | Units | Source | Transformed | |
|---|---|---|---|---|---|
| N.G. | 1,032 | Btu/cubic foo | (1) | 1,032 | Btu/cubic foot |
| Coal | 22.25 | million btu/to | (1) | 22.25 | million btu/ton |

| | | | | |
|---|---|---|---|---|
| Oil | 5.83 | million btu/ba(1) | 0.14 | million btu/gallon |

| Emission FacN.G. | | Coal | Oil |
|---|---|---|---|
| NOx | 0.1357 | 0.6157 | 0.1442 |
| SOx | 0.0006 | 2.5618 | 1.0354 |
| PM-10 | 0.0133 | 0.5573 | 0.0072 |
| CO | 0.0339 | 0.2247 | 0.0361 |
| CO2 | 116.89 | 206.64 | 161.16 |
| Non-Methane | 0.0027 | 0.0022 | 0.0025 |
| Methane | 0.0029 | 0.0027 | 0.0016 |
| Particulate | 0.0133 | 0.7640 | 0.0144 |

Emissions in lb/bu

| | | |
|---|---|---|
| NOx | 8.40E-04 | lb/bu |
| SOx | 3.27E-03 | lb/bu |
| PM-10 | 3.29E-04 | lb/bu |
| CO | 2.47E-04 | lb/bu |
| CO2 | 0.6238 | lb/bu |
| Non-Methane | 1.07E-05 | lb/bu |
| Methane | 9.68E-06 | lb/bu |
| Particulate | 4.50E-04 | lb/bu |

Notes: Emissions factors used for natural gas are for uncontrolled small industrial boilers. Emission factors for oil are for uncontrolled distillate oil fired commercial boilers. Emission factors for coal are for uncontrolled spreader stokers and assumes 1.5% sulfur content. The PM-10 value for coal is from AP-42 table 1.1-8 and differs slightly from the value in AP-42 table 1.1-3.

---

Table 32 Material resource Requirements for Fertilizer and Herbicide Manufacture

(1) The Fertilizer Institute. 1982. The Fertilizer Handbook

(2) Bhat, Mahadev G., Burton C. English, Anthony Turhollow, and Herzron Nyangito. 1993. Energy Use in Synthetic Agricultural Inputs: Revisited, Report prepared by the Department of Agricultural Economics and Rural Sociology, The University of Tennessee, Knoxville, for Biofuels Feedstock Development Program Environmental Sciences Division, Oak Ridge National Laboratory, ORNL/Sub/90-99732/2.

(3) U.S. Department of the Interior, Bureau of Mines. 1994. Mineral Commodity Summaries: 1994

Nitrogen

Nitrogenous fertilizers are primarily manufactured from ammonia, and for corn the predominant form is simply anhydrous ammonia. The most common manufacturing method for ammonia uses natural gas as a feedstock. The use of this natural gas has been accounted for in the energy consumption estimates (the nitrogen in the ammonia comes from the air).

Nitrogen solutions are the next most common N fertilizer type used in corn production. Nitrogen solutions are produced from urea and ammonium nitrate. Ammonium nitrate is again manufactured from ammonia, for which the feedstock energy use is captured in the natural gas energy consumption estimates.

Urea is produced from ammonia and carbon dioxide. Since carbon dioxide is a byproduct of steam reforming of methane (to produce ammonia) and since carbon dioxide is not typically considered a "resource", the material resource requirements for N fertilizers are entirely captured by the use of natural gas as a feedstock.

Phosphatic Fertilizers

Phosphorous is produced from calcium phosphate rock deposits found primarily in Florida and North Carolina . The production of 1 ton of P2O5 requires 3.2 tons of phosphate rock (2). On this basis the resource consumption for corn production is calculated from Table 2, or
1.25 lb/bushel

Potassium

Potassium is mined from deep potassium ore beds or recovered from natural brines such as Searles Lake, CA. The predominant source are deep mines, where potassium is recovered as KCl mixed with other salts. The quantity of KCl used to produce a unit of K20 can be calculated from the stoichiom 0.37 lb/bushel

Sulfur

Sulfur is used both as a primary nutrient in corn production, and also in the manufacture of potassium fertilizers. In fertilizer production sulfur is burned then reacted to form sulfur trioxide. The sulfur trioxide is then mixed with dilute sulfuric acid to form a concentrated solution of sulfuric acid. Finally phosphate rock is treated with sulfuric acid to produce phosp 3.06 tons
tons of sulfuric acid ($H_2SO_4$). The sulfuric acid reacts with phosphate rock according to the simplified reactions :
$Ca_3(PO_4)_2 + 3H_2SO_4 + 6H_2O \rightarrow 2H_3PO_4 + 3CaSO_4{*}H_2O$. The phosphorous is then burned or oxidized to phosphoric acid. According to information provided by Joyce Ober at the Bureau of Mines, one ton of DAP (the most common source of phosphates in Iowa), requires about .431 to 0.918 lb sulfur per pound of $P_2O_5$.

0.01 lb/bu direct application
0.43 lb/bu from phosphoric acid manufacture
0.44 lb/bu total

Sulfur is produced in the U.S. primarily from recovered sulfur at petroleum refineries, natural gas processing plants, and coking plants, which account for 55% of domestic consumption in 1993 (3). About 21% of sulfur production is through Frasch process sulfur mining
The remaining sulfur came from byproduct sulfuric acid, primary pyrites, hydrogen sulfide, and sulfur dioxide.

---

Table 33 Emissions of PM-10 from Crushed Stone Processing Operations

U.S. EPA, AP-42, Table 11.19.2-2.

Units are lb/ton of stone

| PM-10 Emission Category | Controlled | Uncontrolled | Controlled/Uncon | Control Efficiency |
|---|---|---|---|---|
| Screening | 8.40E-04 | 0.015 | 5.60% | 94.40% |
| Primary Crus | - | - | - | - |
| Secondary C | - | - | - | - |
| Tertiary Crus | 5.90E-04 | 0.0024 | 24.58% | 75.42% |
| Fines Crushi | 2.00E-03 | 0.015 | 13.33% | 86.67% |
| Fines Screen | 2.10E-03 | 0.071 | 2.96% | 97.04% |
| Conveyor Tra | 4.80E-05 | 0.0014 | 3.43% | 96.57% |
| Wet Drilling: | - | 8.00E-05 | - | - |
| Truck Unload | - | 1.60E-05 | - | - |
| Truck Loadin | - | 0.0001 | - | - |
| Total (lb/ton o | 5.58E-03 | 0.104996 | - | - |
| Total (lb/bu c | 3.58E-06 | 6.73E-05 | | |

Notes: Based on this data the PM-10 emissions from stone processing are negligible with comparison to PM-10 emissions from Ag. operations in corn production (Table 26).
Thus this emission is not added to total PM-10 emissions.

---

Table 34 Emissions from Phosphate Rock Processing

(1) U.S. EPA, AP-42, Tables 11.21-2 and 11.21-3

(2) The Fertilizer Institute. 1982. The Fertilizer Handbook

Units of lb/ton of total phosphate rock feed

| Emission SouSO2 | CO2 | CO | | Filterable PM-10 |
|---|---|---|---|---|
| Dryer | - | 86 | 0.34 | 4.8 |
| Calciner | - | - | - | 15 |
| Calciner With | 0.0069 | 230 | - | - |

Assuming that output is roughly equivalent to feed quantity, emissions can be converted into lb/bu of corn using the relationship that 3.5 tons of phosphate rock are used to produce one ton of P2O5 (2).

Units of lb/bu of corn

| Emission SouSO2 | CO2 | CO | | Filterable PM-10 |
|---|---|---|---|---|
| Dryer | - | 0.06 | 2.33E-04 | 3.29E-03 |
| Calciner | - | - | - | 1.03E-02 |
| Calciner With | 4.73E-06 | 0.16 | - | - |
| Total | 4.73E-06 | 0.22 | 2.33E-04 | 1.36E-02 |

---

Table 35 Process Related Emissions from Ammonia Manufacture for Nitrogenous Fertilizers

U.S. EPA. 1995. AP-42, Fifth Edition, Table 8.1-1.

All units are in lb/ton of ammonia produced

| Emission SouCO | SO2 | NH3 | CO2 | | Total Organic Compounds |
|---|---|---|---|---|---|
| Desulferizatio | 13.8 | 0.0576 | | | 7.2 |
| Carbon Dioxi | 2 | | 2 | 2,440 | 1.04 |
| Condensate Steam Stripper | | | 2.2 | 6.8 | 1.2 |

Since nitrogenous fertilizer use is given in terms of the nitrogen quantity, these emission factors can be converted into terms of lb/ton of nitrogen. This is done using the ratio of the molecular wt. of ammonia to the molecular wt. of nitrogen. The converted emission factors are then multiplied by the total nitrogen use, in tons.

| | |
|---|---|
| Molecular wt | 14.01 |
| Molecular wt | 1.01 |
| Molecular wt | 17.03 |
| Ratio NH3:N | 1.22 |

All units are in lb/ton of nitrogen produced

| Emission SouCO | SO2 | NH3 | CO2 | | Total Organic Compounds |
|---|---|---|---|---|---|
| Desulferizatio | 16.78 | 0.07 | | | 8.75 |
| Carbon Dioxi | 2.43 | | 2.43 | 2,967 | 1.26 |
| Condensate Steam Stripper | | | 2.67 | 8 | 1.46 |

Finally emissions are converted to units of lb of pollutant per bushel of corn produced using the nitrogen fertilizer use rate in Table 2.

All units are in lb/bu of corn

| Emission SouCO | SO2 | NH3 | CO2 | | Total Organic Compounds |
|---|---|---|---|---|---|
| Desulferizatio | 0.0086 | 3.59E-05 | - | - | 0.0045 |
| Carbon Dioxi | 0.0012 | - | 0.0012 | 1.5217 | 0.0006 |
| Condensate | - | - | 0.0014 | 0.0042 | 0.0007 |
| Total | 0.0099 | 3.59E-05 | 0.0026 | 1.5259 | 0.0059 |

Notes: Since we know the amount of methane (and hence carbon) used as a feedstock for nitrogen fertilizer production we can calculate a bound on process related CO2 emissions.

| | | |
|---|---|---|
| Feedstock M | 21.78 | million btu/ton ammonia |
| | 26.48 | million btu/ton N |
| | 13,241 | Btu/lb N |
| Carbon per u | 14.47 | Million metric tons C/quad |
| | 31.90 | lb C/million btu |
| | 116.89 | lb CO2/million btu |
| | 1.55 | lb CO2/lb N |
| | 3,095 | lb CO2/ton N |

This shows that the CO2 emission factors for process related emissions are based on the carbon value of the feedstock, and the assumption that virtually all carbon is emitted, not used for other purposes.

Table 36 Process Emissions from Urea Manufacture

(1) U.S. EPA. 1995. AP-42, Fifth Edition, Table 8.2-1.

(2) The Fertilizer Institute. 1982. The Fertilizer Handbook

Emission Factors (lb/ton urea)

| Type of Oper | Particulate Uncontrolled | Particulate Controlled | Ammonia Uncontrolled | Ammonia Controlled |
|---|---|---|---|---|
| Solution Formation and Concentratio | 0.021 | - | 18.46 | - |
| Nonfluidized Bed Prilling Agricultural G | 3.8 | 0.063 | 0.87 | - |
| Fluidized Bed Prilling Agricultural G | 6.2 | 0.78 | 2.91 | - |
| Drum Granul | 241 | 0.234 | 2.15 | - |
| Rotary Drum | 7.78 | 0.2 | 0.051 | - |
| Bagging | 0.19 | - | - | - |

| | | Source |
|---|---|---|
| Percentage N | 46% | (2) |

Emission Factors (lb/ton N)

| Type of Oper | Particulate Uncontrolled | Particulate Controlled | Ammonia Uncontrolled | Ammonia Controlled |
|---|---|---|---|---|
| Solution Formation and Concentratio | 0.046 | - | 40.130 | - |
| Nonfluidized Bed Prilling Agricultural G | 8.261 | 0.137 | 1.891 | - |
| Fluidized Bed Prilling Agricultural G | 13.478 | 1.696 | 6.326 | - |
| Drum Granul | 523.913 | 0.509 | 4.674 | - |
| Rotary Drum | 16.913 | 0.435 | 0.111 | - |
| Bagging | 0.413 | - | - | - |

Physical and Chemical Characteristics of Nitrogen Solution
(28% N in solution)

| | | |
|---|---|---|
| Urea N: Amm | 1.04 | (unitless) |
| Urea N | 50.98% | |
| Ammonium N | 49.02% | |

| | | | |
|---|---|---|---|
| Direct Urea N | 0.10 | lb/bu | 41.62% percent |
| Urea N Use R | 0.13 | lb/bu | 58.38% percent |
| Total N Use f | 0.23 | lb/bu | |

Emissions (lb/bu)

| | Particulate | | Ammonia | |
|---|---|---|---|---|
| Type of Oper | Uncontrolled | Controlled | Uncontrolled | Controlled |
| Solution Formation and | | | | |
| Concentratio | 5.24E-06 | - | 4.60E-03 | - |
| Nonfluidized Bed Prilling | | | | |
| Agricultural G | 9.48E-04 | 1.57E-05 | 2.17E-04 | - |
| Fluidized Bed Prilling | | | | |
| Agricultural G | 1.55E-03 | 1.95E-04 | 7.26E-04 | - |
| Drum Granul | 6.01E-02 | 5.84E-05 | 5.36E-04 | - |
| Rotary Drum | 1.94E-03 | 4.99E-05 | 1.27E-05 | - |
| Bagging | 4.74E-05 | - | - | - |
| Average of P | 1.25E-03 | 1.05E-04 | 4.71E-04 | |
| Total including solution formation, and prilling | 1.25E-03 | #VALUE! | 4.80E-03 | |

Notes: The only significant particulate emission source relative to other sources in corn production is uncontrolled emissions from drum granulation. By contrast controlled emissions are about 0.1% of uncontrolled emissions from this source. Furthermore, only a fraction of urea production is granular. More than 50% of urea is used in nitrogen solutions, in which case granulation is not required.
Reference (1) also states that wet scrubbers are standard equipment for drum granulators. Based on this information it is assumed that particulate emissions from urea manufacture are negligible.

Ammonia emissions are not negligible. The emission factors for ammonia in urea formation and concentration are much larger than ammonia emission factors in ammonia manufacture. The total emission factor used here is generated on the assumption that all urea passes through the concentration operation, that solid urea is produced through uncontrolled prilling operations, and the average factor for the two types of prilling operations is used. Assumptions about the granulation method have little effect on the emission factor since granulation emissions are outweighed by solution formation and concentration emissions.

---

Table 37 Process Emissions from Ammonium Nitrate Manufacture

(1) U.S. EPA. 1995. AP-42, Fifth Edition, Table 8.3-2.

(2) The Fertilizer Institute. 1982. The Fertilizer Handbook

Ammonium Nitrate is not itself an important fertilizer type in Iowa, suggesting that its use in corn production is limited. Ammonium nitrate is a constituent of nitrogen solutions, however, which are the second most common form of nitrogen application in Iowa. For this reason it is necessary to evaluate the significance of process related emissions from ammonium nitrate manufacture. These are limited to neutralizing and evaporation/concentration processes since it is not necessary to produced solid forms of ammonium nitrate for nitrogen solution manufacture.

Emission Factors (lb/ton)

| | Particulate | | Ammonia | Nitric Acid | |
|---|---|---|---|---|---|
| Process | Controlled | Uncontrolled | Uncontrolled | Controlled | Notes |
| Neutralizer | 4.345 | 0.217 | 18.44 | 1.042 | Ammonia emission factor given as range from 0.86 to 36.02. Nitric acid from 0.084 to 2 |
| Evaporation/ | 0.52 | - | 16.97 | - | Ammonia emission factor given as range from 0.54 to 33.4. |

Source

Ammonium N 34% (2)

Emission Factor (lb/ton N)

| Process | Particulate Controlled | Uncontrolled | Ammonia Uncontrolled | Nitric Acid Controlled |
|---|---|---|---|---|
| Neutralizer | 12.78 | 0.64 | 54.24 | 3.06 |
| Evaporation/ | 1.53 | - | 49.91 | - |

| | |
|---|---|
| Urea N: Amm | 1.04 (unitless) |
| Urea N | 50.98% |
| Ammonium N | 49.02% |

Emission Rate (lb/bu)

| Process | Particulate Controlled | Uncontrolled | Ammonia Uncontrolled | Nitric Acid Controlled |
|---|---|---|---|---|
| Neutralizer | 8.23E-04 | 4.11E-05 | 3.49E-03 | 1.97E-04 |
| Evaporation/ | 9.85E-05 | - | 3.21E-03 | - |
| Total | 9.21E-04 | 4.11E-05 | 6.71E-03 | 1.97E-04 |

Notes: Particulate emissions from ammonium nitrate manufacture are negligible relative to PM-10 emissions from tilling operations. Lacking data on the use of particulate controls, these emissions will not be included in total particulate or PM-10 emissions. Ammonia emissions are significant relative to emissions of ammonia from urea and ammonia manufacturing operations. Lacking additional data the sum of the mid-range values for uncontrolled ammonia emissions and controlled nitric acid emissions are used.

---

Table 38 Process Emissions from Ammonium Phosphate Manufacture

(1) U.S. EPA. 1995. AP-42, Fifth Edition, Table 8.5.3-1.

(2) The Fertilizer Institute. 1982. The Fertilizer Handbook

Emission Factors (lb/ton)

| Process | Particulate | Ammonia | Fluoride (as F) | SO2 |
|---|---|---|---|---|
| Reactor/Amm | 1.52 | - | 0.05 | - |
| Dryer/cooler | 1.5 | 0.02 | 0.04 | - |
| Product sizin | 0.06 | 0.08 | 0.002 | - |
| Total Plant | 0.68 | 0.14 | 0.04 | 0.08 |

Fraction P2O 46% (2)

Emission Factors (lb/ton P2O5)

| Process | Particulate | Ammonia | Fluoride | SO2 |
|---|---|---|---|---|
| Reactor/Amm | 3.30 | - | 0.11 | - |
| Dryer/cooler | 3.26 | 0.04 | 0.09 | - |
| Product sizin | 0.13 | 0.17 | 0.004 | - |
| Total Plant | 1.48 | 0.30 | 0.09 | 0.174 |

Emission Rate (lb/bu)

| Process | Particulate | Ammonia | Fluoride | SO2 |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| Reactor/Amm | 6.47E-04 | - | - | - |
| Dryer/cooler | 6.39E-04 | 8.51E-06 | - | - |
| Product sizin | 2.55E-05 | 3.41E-05 | 8.51E-07 | - |
| Total Plant | 2.90E-04 | 5.96E-05 | 1.70E-05 | 3.41E-05 |

Note: For particulate and ammonia the total emission factor is not the sum of the process emission factors, but is instead an aggregate value from a different source. The EPA quality rating for these values is also high, as opposed to the process level values, for which it is low. As such, emissions for corn production are taken from the total plant row.

---

Table 39 Process Emissions from Nitric Acid Manufacture (used in ammonium nitrate manufacture)

(1) U.S. EPA. 1995. AP-42, Fifth Edition, Table 8.8-1.

(2) The Fertilizer Institute. 1982. The Fertilizer Handbook

Nitric acid is used in the manufacture of ammonium nitrate. Since these emissions are not included in the emissions from ammonium nitrate manufacture they are included here.

Emission Factors (lb/ton)

| Source | NOx |
|---|---|
| Weak Acid P | 57 |
| New Source | 3 |
| Catalytic Reduction | |
| Natural Gas | 0.4 |
| Hydrogen | 0.8 |
| N.G./Hydroge | 0.9 |
| Extended Absorption | |
| Single-Stage | 1.9 |
| Dual-Stage P | 2.1 |
| Chilled Absor | 2.2 |
| High-Strengt | 10 |

Ratio of HNO 0.79
(nitric acid to ammonium nitrate)
NH3 + HNO3 -> NH4NO3

Emission Factors (lb/ton ammonium nitrate)

| Source | NOx |
|---|---|
| Weak Acid P | 44.87 |
| New Source | 2.36 |
| Catalytic Reduction | |
| Natural Gas | 0.31 |
| Hydrogen | 0.63 |
| N.G./Hydroge | 0.71 |
| Extended Absorption | |
| Single-Stage | 1.50 |
| Dual-Stage P | 1.65 |
| Chilled Absor | 1.73 |
| High-Strengt | 7.87 |

Fraction N in 0.35

Emission Factors (lb/ton N)

| Source | NOx |
|---|---|
| Weak Acid P | 128.21 |
| New Source | 6.75 |
| Catalytic Reduction | |
| Natural Gas | 0.90 |
| Hydrogen | 1.80 |
| N.G./Hydroge | 2.02 |
| Extended Absorption | |
| Single-Stage | 4.27 |
| Dual-Stage P | 4.72 |
| Chilled Absor | 4.95 |
| High-Strengt | 22.49 |

| | | |
|---|---|---|
| Urea N: Amm | 1.04 | (unitless) |
| Urea N | 50.98% | |
| Ammonium N | 49.02% | |

Emission (lb/bu)

| Source | NOx |
|---|---|
| Weak Acid P | 8.26E-03 |
| New Source | 4.35E-04 |
| Catalytic Reduction | |
| Natural Gas | |
| Hydrogen | 1.16E-04 |
| N.G./Hydroge | 1.30E-04 |
| Extended Absorption | |
| Single-Stage | 2.75E-04 |
| Dual-Stage P | 3.04E-04 |
| Chilled Absor | 3.19E-04 |
| High-Strengt | 1.45E-03 |
| Total Excludi | 9.84E-03 |

Notes: Uncontrolled emissions rates from weak acid plant tailgas are the only emissions that are significant relative to fuel related emissions from the corn production cycle. The uncon 19.38% of fuel related NOx emissions. While this would be a significant contribution many techniques are employed to reduce tail gas emissions including extended absorption and catalytic reduction. Also,New Source Performance Standards for nitrogen emissions (expressed as $N_2O$) for new and modified plants are 3 lb/ton of nitric acid. At this emission rate the NOx contributions from nitric acid manufac 1.02% of fuel related NOx emissions. Lacking information to accurately estimate actual controlled emissions, they will be neglected.

---

Table 40 Process Emissions from the Manufacture of Phosphoric Acid

(1) U.S. EPA. 1995. AP-42, Fifth Edition, Table 8.9-1.

(2) The Fertilizer Institute. 1982. The Fertilizer Handbook

Phosphoric acid used in fertilizer manufacture is produced primarily using a wet process method. The factors given below are for wet process manufacture.

Emission Factors (lb/ton $P_2O_5$)

| | Fluoride | | |
|---|---|---|---|
| Source | Controlled | | Uncontrolled |
| Reactor | | 3.80E-03 | 0.38 |
| Evaporator | | 4.40E-05 | 0.0044 |
| Belt Filter | | 6.40E-04 | 0.064 |
| Belt Filter Va | | 1.50E-04 | 0.015 |
| Gypsum Sett- | | | |

Emission Rate (lb/bu)

| Source | Fluorine Controlled | Uncontrolled |
|---|---|---|
| Reactor | 7.44E-07 | 7.44E-05 |
| Evaporator | 8.62E-09 | 8.62E-07 |
| Belt Filter | 1.25E-07 | 1.25E-05 |
| Belt Filter Va | 2.94E-08 | 2.94E-06 |
| Gypsum Sett - | | |
| Total | 9.08E-07 | 9.08E-05 |

Notes: Uncontrolled fluorine emissions from phosphoric acid manufacture are similar to controlled emissions from ammonium phosphate manufacture.
For phosphoric acid, the control efficiency used is 99%, similar to the value given for the use of baghouses in GTSP manufacture. On this basis controlled emissions from phosphoric acid manufacture are only about 1% of controlled emissions from phosphoric acid manufacture.
For the sake of consistency, and lack further data on the relative penetration of controls in this industry, the controlled emission rate is used.

---

Table 41 Process Emissions from Sulfuric Acid Manufacture (used in phosphoric acid manufacture)

(1) U.S. EPA. 1995. AP-42, Fifth Edition, Table 8.8-1.

(2) The Fertilizer Institute. 1982. The Fertilizer Handbook

Sulfuric acid is used in the manufacture of phosphoric acid which is used in the manufacture of phosphate fertilizers. Emission consist primarily of sulfur dioxide and acid mist. Sulfur dioxide emissions are primarily a function of the conversion efficiency from SO2 to SO3 in the plant.

Emission Factors (lb/ton sulfuric acid)

| Conversion | ESO2 Emissions |
|---|---|
| 93 | 96 |
| 94 | 82 |
| 95 | 70 |
| 96 | 55 |
| 97 | 40 |
| 98 | 26 |
| 99 | 14 |
| 99.5 | 7 |
| 99.7 | 4 |
| 100 | 0 |

| | | Source |
|---|---|---|
| Sulfuric Acid | 2.87 | Conversion factor for sulfuric acid to DAP provided by Joyce Ober, sulfur specialist, Bureau of Mines |

Emission Factor (lb/ton P2O5)

| Conversion | ESO2 Emissions |
|---|---|
| 93 | 275.52 |
| 94 | 235.34 |
| 95 | 200.9 |
| 96 | 157.85 |
| 97 | 114.8 |
| 98 | 74.62 |
| 99 | 40.18 |
| 99.5 | 20.09 |
| 99.7 | 11.48 |
| 100 | 0 |

Emission Rate (lb/bu)

| Conversion | ESO2 Emissions |
|---|---|
| 93 | 0.0540 |
| 94 | 0.0461 |
| 95 | 0.0393 |
| 96 | 0.0309 |
| 97 | 0.0225 |
| 98 | 0.0146 |
| 99 | 0.0079 |
| 99.5 | 0.0039 |
| 99.7 | 0.0022 |
| 100 | 0.0000 |

Notes: Sulfur dioxide emissions are highly correlated with conversion efficiency. Typical conversion efficiencies are given in AP-42 as 95 to 98%. Sufur emissions can be controlled using standard sulfur capture technologies. New Source Performance Standards are also set quite low, at 4 lb/ton of product. Assuming that new plants comply with NSPS limits, but that old plants exist with higher emissions, the emission rate used here is at the upper end of conversion efficiency estimates.

Acid Mist Emission Factors (lb/ton H2SO4) (Where values are given as a range, the midrange is used)

| Raw Materia | Uncontrolled | Controlled |
|---|---|---|
| Recovered S | 0.574 | - |
| Elemental Su | - | 0.128 |
| Bright Virgin | 1.7 | - |
| Dark Virgin S | 3.3 | 2.06 |
| Spent Acid | 2.3 | 0.34 |

Acid Mist Emission Factors (lb/ton P2O5)

| Raw Materia | Uncontrolled | Controlled |
|---|---|---|
| Recovered S | 1.64738 | - |
| Elemental Su | - | 0.36736 |
| Bright Virgin | 4.879 | - |
| Dark Virgin S | 9.471 | 5.9122 |
| Spent Acid | 6.601 | 0.9758 |

Acid Mist Emissions (lb/bu)

| Raw Materia | Uncontrolled | Controlled |
|---|---|---|
| Recovered S | 3.23E-04 | - |
| Elemental Su | - | 7.19E-05 |
| Bright Virgin | 9.56E-04 | - |
| Dark Virgin S | 1.85E-03 | 1.16E-03 |
| Spent Acid | 1.29E-03 | 1.91E-04 |
| Average | 1.41E-03 | 6.15E-04 |
| Average (Co | 1.01E-03 | |

Notes: According to AP-42 about 81% of sulfuric acid production is from elemental sulfur burning. Average emission factors are calculated above using the elemental, bright virgin, and dark virgin sulfur factors.

The uncontrolled and controlled factors are then averaged.

| | | |
|---|---|---|
| Carbon Dioxi | 8.1 | lb/ton sulfuric acid |
| | 23.247 | lb/ton P2O5 |
| | 0.0046 | lb/bu |

Notes: Carbon dioxide emissions are negligible relative to other sources and are thus neglected.

---

Table 42 Air Emissions from Pesticide Use


(1) U.S. EPA. 1995. AP-42, Fifth Edition, Section 9.2.2.

(2) Personal Communication with David Pike, Agriculture Extensionist, University of Illinois, Department of Agronomy, September 26, 1995.

(3) Personal Communication with Van Johnson, Pesticide Specialist, USDA NASS, September 28, 1995.

(4) Personal Communication with Bob Hartzler, Iowa Ag. Extension, University of Iowa, September 22, 1995.

(5) United States Department of Agriculture, Economic Research Service. 1994. Agricultural Resource and Environmental Indicators, USDA/ERS, Ag. handbook 705, Washington, D.C.

(6) Personal Communication with Tom Lapp, Midwest Research Institute, September 29, 1995.


Pesticide Types Used on Illinois Corn (2) Product formulation data was provided by Van Johnson of the USDA, NASS.

| Pesticide Typ | Active Ingredient | Brand | Formulation Type | Formulation S | Alachlor | Atrazine | Fraction Prin | Fraction Inert Ingredient | Fraction of To | Normalized Fr | Pest. use/bu co | a.i. use/bu co | Atrazine/bu c | Total VOC's (lb/bu corn) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Herbicides | Alachlor | Bullet | liquid | 4 | 2.5 | 1.5 | 29.99% | 52.02% | 30% | 35.29% | 4.72E-03 | 1.42E-03 | 8.49E-04 | 4.91E-04 |
| | | Lasso (4EC) | liquid | 4 | 4 | 0 | 47.98% | 52.02% | 20% | 23.53% | 1.97E-03 | 9.43E-04 | 0.00E+00 | 2.05E-04 |
| | | Lariat (4F) | liquid | 4 | 2.5 | 1.5 | 29.99% | 52.02% | 10% | 11.76% | 1.57E-03 | 4.72E-04 | 2.83E-04 | 1.64E-04 |
| | | Lasso Micro- | micro-encapsulat | 4 | 4 | 0 | 47.98% | 52.02% | 25% | 29.41% | 2.46E-03 | 1.18E-03 | 0.00E+00 | 2.56E-04 |
| | | | | | | | | | 85% | | 1.07E-02 | 4.01E-03 | 1.13E-03 | 1.12E-03 |
| | | | | | Metalachlor | Atrazine | | | | | | | | |
| | Metalachlor | Dual 4E | liquid | 4 | 4 | 0 | 47.98% | 52.02% | 50% | 50.00% | 5.11E-03 | 2.45E-03 | 0.00E+00 | 5.32E-04 |
| | | Bicep 6L | liquid | 6 | 3.33 | 2.67 | 39.94% | 28.03% | 35% | 35.00% | 4.30E-03 | 1.72E-03 | 1.38E-03 | 2.41E-04 |
| | | Dual 25G | granular | 0.25 | 25 | 0 | 25.00% | 75.00% | 15% | 15.00% | 2.94E-03 | 7.36E-04 | 0.00E+00 | 5.52E-04 |
| | | | | | | | | | 100% | | 1.24E-02 | 4.91E-03 | 1.38E-03 | 1.33E-03 |
| | | | | | Atrazine | Other | | | | | | | | |
| | Atrazine | Bicep 6L | liquid | 6 | 2.67 | 3.33 | 32.03% | 28.03% | 25% | 25.00% | 4.30E-03 | 1.38E-03 | 1.38E-03 | 3.09E-04 |
| | | Atrazine 4L | liquid | 4 | 4 | 0 | 47.98% | 52.02% | 52% | 52.00% | 6.76E-03 | 3.25E-03 | | 7.04E-04 |
| | | Bullet | liquid | 4 | 1.5 | 2.5 | 17.99% | 52.02% | 15% | 15.00% | 4.72E-03 | 8.49E-04 | 8.49E-04 | 6.04E-04 |
| | | Marksman | liquid | 4 | 2.1 | 1.1 | 25.19% | 52.02% | 8% | 8.00% | 1.98E-03 | 4.99E-04 | | 2.97E-04 |
| | | | | | | | | | 100% | | 1.78E-02 | 5.97E-03 | | |
| | | | | | | | | | | | Actual Atrazine | 6.24E-03 | | |
| | | | | | | | | | | Percent Accou | 95.67% | Atrazine from | 6.80E-04 | 1.91E-03 |
| | | | | | | | | | | | | Total Atrazin | 2.91E-03 | |
| | | | | | | | | | | | | Total Atrazin | 6.24E-03 | |
| | | | | | Cyanazine | Atrazine | | | | | | | | |
| | Cyanazine | Extrazine 4L | liquid | 4 | 3 | 1 | 35.98% | 52.02% | 40% | 42.11% | 3.78E-03 | 1.36E-03 | 4.53E-04 | 3.93E-04 |
| | | Extrazine 90D | dry flowable | 90 | 0.675 | 0.225 | 67.50% | 10.00% | 20% | 21.05% | 1.01E-03 | 6.80E-04 | 2.27E-04 | 2.82E-05 |
| | | Bladex 80WP | wettable powder | 80 | 0.8 | 0 | 80.00% | 20.00% | 8% | 8.42% | 3.40E-04 | 2.72E-04 | 0.00E+00 | 1.70E-05 |
| | | Bladex 4L | liquid | 4 | 4 | 0 | 47.98% | 52.02% | 12% | 12.63% | 8.50E-04 | 4.08E-04 | 0.00E+00 | 8.85E-05 |
| | | Bladex 90DF | dry flowable | 90 | 0.9 | 0 | 90.00% | 10.00% | 15% | 15.79% | 5.67E-04 | 5.10E-04 | 0.00E+00 | 1.59E-05 |
| | | | | | | | | | 95% | | 6.54E-03 | 3.23E-03 | 6.80E-04 | 5.43E-04 |
| Insecticides | Chlorpyrifos | Lorsban 15G | granular | 15 | | | 0.15 | 85.00% | 95% | 100.00% | 3.27E-02 | 4.91E-03 | 0 | 6.95E-03 |
| | Fonofos | Dyfonate II 2 | granular | 20 | | | 0.2 | 80.00% | 95% | 100.00% | 2.45E-02 | 4.91E-03 | 0 | 4.91E-03 |
| | Turbufos | Counter (15G | granular | 15 | | | 0.15 | 85.00% | 80% | 80.00% | 2.62E-02 | 3.93E-03 | 0 | 5.56E-03 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Counter 20C ? | 20 | 0.2 | 80.00% | 20% | 20.00% | 4.91E-03 | 9.81E-04 | | 0 | 9.81E-04 | |
| | | | | | Total Pesticid | 1.36E-01 | | Total VOC's | | 2.33E-02 | lb/bu |

Notes: The above table is quite confusing, and I appologize for the convoluted estimation methodology. The complexity is caused by the fact that pesticides are often sold in formulations containing more than one active ingredient. Thus if you treat a 4L pesticide as having 4 lb/gallon of the primary a.i., you will end up double counting the inert portion since the pesticide is actually delivering two forms of a.i. which together sum to 4L. To account for this I added columns in which I calculate the quantity of pesticide used to deliver the appropriate amount of the primary a.i., based on the fraction of each brand used to meet the need for that a.i. These fractions were normalized to 100% to simulate complete coverage by the most important brands cited by Dave Pike. I then estimate the amount of atrazine, the secondary chemical, that comes along for the ride. Finally, I summed up the atrazine from combination forms in the atrazine section, instead of calculating it from the fraction of atrazine applied in various forms. I then modified the fractions for atrazine to try and balance the total atrazine use. This was done by raising the estimated fraction of atra 95.67% of actual use. I then delete the contribution of dual form atrazine formulations from the contribution to the VOC emissions, w 17.17% percent of total pesticide use (by gross pesticide wt.)

VOC emissions are estimated using the data below on the fraction of inert ingredient that are VOC's. These are applied to the total inert ingredient quantities calculated in the above table. Total VOC emissions are then summed. I have included VOC emissions from pesticides in the category non-methane organic compounds, which is a broader class of organics. For a good description of the classification of organics see AP-42 (1995) pages 6 and 7.

I should also note that I made some assumptions about the brands used to supply granular pesticides. Dave Pike did not give brand specific data for these, only the formulation type and strength. In most cases there is only one brand listed of each strength in the data provided by Van Johnson. Thus I used that particular brand data for the pesticide type and strength of interest.

Air Emissions

| Active Ingred | From Table 2 | | Source: AP-42 Table 9.2.2-1 | | Source: AP-42 Table 9.2.2-4 | | | Surface incorporation fraction estimated based on conversations with Bob Hartzler and Dave Pike. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Emission Fac | Emission Factor | | Surface Application | Total Emissions | | Percent of a.i. Volatilized |
| Pesticide | Use Rate | Units | Vapor Pressure | Units | Surface Applic | Soil Incorpor | Units | Fraction | Active Ingredi | Units | |
| Alachlor | 4.01E-03 | lb/bu corn | 1.4E-05 | mm Hg at 20 | 700 | 42 | lb/ton | 70% | 1.01E-03 | lb/bu | 25.13% |
| Metholachlor | 4.91E-03 | lb/bu corn | 3.1E-05 | mm Hg at 20 | 700 | 42 | lb/ton | 70% | 1.23E-03 | lb/bu | 25.13% |
| Atrazine | 6.24E-03 | lb/bu corn | 2.9E-07 | mm Hg at 20 | 700 | 5.4 | lb/ton | 85% | 1.86E-03 | lb/bu | 29.79% |
| Cyanazine | 3.23E-03 | lb/bu corn | 1.6E-09 | mm Hg at 20 | 700 | 5.4 | lb/ton | 85% | 9.62E-04 | lb/bu | 29.79% |
| Chlorpyrifos | 7.34E-04 | lb/bu corn | 1.7E-05 | mm Hg at 20 | 700 | 42 | lb/ton | 100% | 2.57E-04 | lb/bu | 35.00% |
| Fonofos | 2.57E-04 | lb/bu corn | 3.4E-04 | mm Hg at 20 | 1160 | 104 | lb/ton | 100% | 1.49E-04 | lb/bu | 58.00% |
| Terbufos | 6.81E-04 | lb/bu corn | 3.2E-04 | mm Hg at 20 | 1160 | 104 | lb/ton | 100% | 3.95E-04 | lb/bu | 58.00% |

Notes: Estimation method described in AP-42. There is some question of what the application method is for insecticides. They are applied using a planter attachment, and are in granular form. Rod Williamson of the Iowa Corn Growers Association suggests that the granules would thus end up at about the depth of the corn seed, or 1-2 inches. Discussions with Tom Lapp, who developed the section for EPA, suggest that this is not what is referred to as soil incorporated. Instead this is meant to apply to pesticides that are actually injected into the soil. This would more commonly occur with liquid or gaseous forms of pesticides. Accordingly the insecticides are treated as 100% surface application.

Average VOC Content of Pesticide Inert Ingredient Portion (1)

| | |
|---|---|
| Liquid | 20% |
| Wettable Pow | 25% |
| Microencaps | 23% |
| Dry Flowable | 28% |
| Granule | 25% |

EOF

e (Ali and McBride 1994). This energy
Shapouri uses an energy use estimate
980). The exact value of 180,000 btu/lb does not appear
omparison of the 1980 estimates reveals
put hauling, suggesting at least some double
omparitive values in Green (1987). Both references
formation the more recent estimate is used. This result
y use for fertilizer manufacture is difficult to
Lorenz appear to rely on estimates
has been used in conjunction with data about
differ little. The Lorenz values are significantly
ng, and application, which would account for much of the difference.
focussed on international uses of fertilizers. Since most U.S.
timate of enery use for irrigation (18,000 Btu/bu), derived
rom 9 mid-western states to estimate on farm energy
account for much of the difference in over energy

Emissions by Sector and Type
(lb/bu)

Fraction of Emissions by S

| Emission Cat | Tilling Opera (Table 26) | Nitrogenous Fuel Consum (Table 27) | Process Emis Ammonia Ma (Table 35) | Limestone Production (Table 24) | Phosphate R Processing (Table 34) | Farm Fuel Use (Table 29) | Corn Drying (Table 30) | Unallocated Emissions (Table 31) | Urea Manufacture (Table 36) | Ammonium N Manufacture (Table 37) | Ammonium P Manufacture (Table 38) | Phosphoric A Manufacture (Table 40 | Sulfuric Acid Manufacture (Table 41) | Nitric Acid Manufacture (Table 39) | Pesticide Use (Table 42) | Total Emissions | | Sum Excluding Nitric Acid MFG | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NOx | - | 3.28E-03 | - | 0.00161 | - | 3.65E-02 | 4.01E-04 | 0.0008 | - | - | - | - | - | 9.84E-03 | - | 0.0524 | NOx | 0.0426 | NOx |
| SOx | - | 6.37E-06 | 3.59E-05 | - | 4.73E-06 | 2.31E-03 | 2.20E-06 | 0.0033 | - | - | 3.41E-05 | - | 1.46E-02 | - | - | 2.03E-02 | SOx | | SOx |
| PM-10 | 0.348 | 1.46E-04 | - | - | 1.36E-02 | - | 4.28E-05 | 0.0003 | - | - | - | - | - | - | - | 3.62E-01 | PM-10 | | PM-10 |
| CO | - | 4.25E-04 | 0.0099 | 0.00138 | 2.33E-04 | 1.41E-01 | 8.09E-05 | 0.0002 | - | - | - | - | - | - | - | 1.53E-01 | CO | | CO |
| CO2 | - | 1.28 | 1.5259 | 0.29174 | 2.17E-01 | 2.11E+00 | 8.76E-01 | 0.6238 | - | - | - | - | - | - | - | 6.93E+00 | CO2 | | CO2 |
| Non-Methane | - | 1.50E-05 | 0 | - | - | - | 2.56E-05 | 0.0000 | - | - | - | - | - | - | 2.33E-02 | 2.33E-02 | Non-Methane VOC's | | Non-Methane |
| Methane | - | 3.07E-06 | - | - | - | - | 7.04E-06 | 0.0000 | - | - | - | - | - | - | - | 1.98E-05 | Methane | | Methane |
| Particulate | - | - | - | - | - | 3.74E-03 | 1.24E-06 | 0.0005 | - | - | 2.90E-04 | - | - | - | - | 4.48E-03 | Particulate | | Particulate |
| Hydrocarbon | - | - | - | 0.00043 | - | 9.57E-03 | - | - | - | - | - | - | - | - | - | 1.00E-02 | Hydrocarbons | | Hydrocarbon |
| Aldehydes | - | - | - | - | - | 4.70E-04 | - | - | - | - | - | - | - | - | - | 4.70E-04 | Aldehydes | | Aldehydes |
| Ammonia | - | - | 0.0026 | - | - | - | - | - | 0.00480008 | 6.71E-03 | 5.96E-05 | - | - | - | - | 1.42E-02 | Ammonia | | Ammonia |
| Nitric Acid | - | - | - | - | - | - | - | - | - | 1.97E-04 | - | - | - | - | - | 1.97E-04 | Nitric Acid | | Nitric Acid |
| Fluoride | - | - | - | - | - | - | - | - | - | - | 1.70E-05 | 9.08E-07 | - | - | - | 1.79E-05 | Fluoride | | Fluoride |
| Acid Mist | - | - | - | - | - | - | - | - | - | - | - | - | 1.01E-03 | - | - | 1.01E-03 | Acid Mist | | Acid Mist |

h only the

ighting times emission factor

| | Gas Trucks | | | Light Duty Diesel | | | | Heavy Diesel Trucks | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total Hydro. | CO | NOx | Fraction | Total Hydro. | CO | NOx | Fraction | Total Hydro. | CO | NOx |
| 1 | 0 | 0 | 0 | | 0 | 0 | 0 | | 0 | 0 | 0 |
| 2 | 0.3944 | 1.7952 | 0.612 | | 0.0408 | 0.1632 | 0.1224 | | 0.34 | 1.1288 | 1.5096 |
| 3 | 0.3596 | 1.6936 | 0.5568 | | 0.0464 | 0.1392 | 0.1044 | | 0.3016 | 1.0556 | 1.334 |
| 4 | 0.3168 | 1.5444 | 0.4851 | | 0.0396 | 0.1287 | 0.099 | | 0.2673 | 0.9801 | 1.188 |
| 5 | 0.289 | 1.4025 | 0.4335 | | 0.034 | 0.1105 | 0.085 | | 0.238 | 0.8925 | 1.037 |
| 6 | 0.2592 | 1.2744 | 0.3888 | | 0.036 | 0.1008 | 0.072 | | 0.2088 | 0.7992 | 0.9 |
| 7 | 0.2294 | 1.1408 | 0.341 | | 0.031 | 0.0868 | 0.0682 | | 0.186 | 0.7192 | 0.7874 |
| 8 | 0.2014 | 1.0123 | 0.2968 | | 0.0265 | 0.0742 | 0.0583 | | 0.1643 | 0.6413 | 0.6837 |
| 9 | 0.1755 | 0.8865 | 0.2565 | | 0.0225 | 0.0675 | 0.0495 | | 0.144 | 0.5625 | 0.5895 |
| 10 | 0.1824 | 1.5808 | 0.1976 | | 0.0228 | 0.057 | 0.0418 | | 0.1254 | 0.5016 | 0.6802 |
| 11 | 0.1716 | 1.6566 | 0.1716 | | 0.0198 | 0.0495 | 0.0396 | | 0.132 | 0.4521 | 0.6006 |
| 12 | 0.3584 | 4.4296 | 0.1568 | | 0.0168 | 0.0448 | 0.0448 | | 0.1568 | 0.4144 | 0.5292 |
| 13 | 0.312 | 3.8496 | 0.1344 | | 0.0144 | 0.0384 | 0.0384 | | 0.1368 | 0.3624 | 0.4536 |
| 14 | 0.262 | 3.304 | 0.114 | | 0.012 | 0.032 | 0.034 | | 0.116 | 0.308 | 0.378 |
| 15 | 0.2376 | 3.0204 | 0.1026 | | 0.0126 | 0.0306 | 0.0306 | | 0.1206 | 0.3042 | 0.369 |
| 16 | 0.207 | 2.7375 | 0.0915 | | 0.0105 | 0.0255 | 0.0285 | | 0.102 | 0.258 | 0.3075 |
| 17 | 0.1807 | 2.4024 | 0.0793 | | 0.0182 | 0.0312 | 0.0247 | | 0.0949 | 0.2626 | 0.3224 |
| 18 | 0.2013 | 2.3221 | 0.0704 | | 0.0154 | 0.0275 | 0.022 | | 0.0814 | 0.2255 | 0.2728 |
| 19 | 0.1782 | 2.1717 | 0.0657 | | 0.0135 | 0.0225 | 0.018 | | 0.0675 | 0.1863 | 0.2232 |
| 20 | 0.8955 | 10.9485 | 0.333 | | 0.0675 | 0.1125 | 0.09 | | 0.3375 | 0.9405 | 1.116 |
| | 5.412 | 49.1729 | 4.8874 | | 0.5003 | 1.3424 | 1.0712 | | 3.3209 | 10.9948 | 13.2817 |

4.91E-04

10.40%

ector

| Tilling Opera (Table 26) | Nitrogenous Fuel Consum (Table 27) | Process Emis Ammonia Ma (Table 35) | Limestone Production (Table 24) | Phosphate R Processing (Table 34) | Farm Fuel Use (Table 29) | Corn Drying (Table 30) | Unallocated Emissions (Table 31) | Urea Manufacture (Table 36) | Ammonium N Manufacture (Table 37) | Ammonium P Manufacture (Table 38) | Phosphoric A Manufacture (Table 40 | Sulfuric Acid Manufacture (Table 41) | Nitric Acid Manufacture (Table 39) | Pesticide Use (Table 42) | Total Emissions | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| - | 8% | - | 4% | - | 86% | 1% | 2% | - | - | - | - | - | 19% | - | 100% | NOx |
| - | 0% | 0% | - | 0% | 11% | 0% | 16% | - | - | - | - | 72% | - | - | 100% | SOx |
| 96% | 0% | - | - | 4% | - | 0% | 0% | - | - | - | - | - | - | - | 100% | PM-10 |
| - | 0% | 6% | 1% | 0% | 92% | 0% | 0% | - | - | - | - | - | - | - | 100% | CO |
| - | 18% | 22% | 4% | 3% | 30% | 13% | 9% | - | - | - | - | - | - | - | 100% | CO2 |
| - | 0% | 0% | - | - | - | 0% | 0% | - | - | - | - | - | - | 99.78% | 100% | Non-Methane VOC's |
| - | 16% | - | - | - | - | 36% | 49% | - | - | - | - | - | - | - | 100% | Methane |
| - | - | - | - | - | 83% | 0% | 10% | - | - | 6% | - | - | - | - | 100% | Particulate |
| - | - | - | 4% | - | 96% | - | - | - | - | - | - | - | - | - | 100% | Hydrocarbons |
| - | - | - | - | - | 100% | - | - | - | - | - | - | - | - | - | 100% | Aldehydes |
| - | - | 18% | - | - | - | - | - | 34% | 47% | - | - | - | - | - | 100% | Ammonia |
| - | - | - | - | - | - | - | - | - | 100% | - | - | - | - | - | 100% | Nitric Acid |
| - | - | - | - | - | - | - | - | - | - | 95% | 5% | - | - | - | 100% | Fluoride |
| - | - | - | - | - | - | - | - | - | - | - | - | 100% | - | - | 100% | Acid Mist |

**Sheet Title:** Corn Transportation and Storage — **Last Modified** 10/03/95

**Sheet Description:**

This sheet includes the life-cycle inventory components for the transport of corn from the producer to a refining facility, including intermediate storage and processing common with corn. Contrary to some literature assumptions about the primary mode of transport, because of the large volumes of corn consumed at typical facilities, the primary mode is rail. Corn is also most commonly shipped to a grain elevator for storage before shipping to the mill. At the grain elevator several processing operations are carried out. The impact of these operations is included here.

**References/Citations:**


Blanchard, Paul H. 1992. Technology of Corn Wet Milling and Associated Processes, Industrial Chemical Library, vol. 4, Elsevier Press, New York.

2 Baumel, C. Philip, Charles R. Hurburgh, and Tenpao Lee. 1985. Estimates of Total Fuel Consumption in Transporting Grain from Iowa to Major Grain Importing Countries by Alternative Modes and Routes: Special Report 90, Iowa Agricultural and Home Economics Experiment Station, Iowa University of Science and Technology, Ames, Iowa.

3 Baumel, C. Philip, Stephen Baumhover, Michael A. Lipsman, and Marty J. McVey. 1991. Alternative Investments in the Rural Branch Railroad and County Road Systems, Midwest Transportation Center, Iowa State University, Ames, Iowa.

4 Chambers, R.S., et al. 1979. Gasohol: Does It or Doesn't It Produce Positive Net Energy, Science, vol. 206, November 1979, pp. 789-795.

5 Davis, Stacy C. 1994. Transportation Energy Data Book: Edition 14, Oak Ridge National Laboratory, ORNL-6798.

6 DeLuchi, M. 1993. Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity, Argonne National Laboratory, ANL/ESD/TM-22, Vol. 2.

7 Giampietro, M., and David Pimentel. 1990. Alcohol and Biogass Production from Biomass, Critical Reviews in Plant Sciences, Vol. 9, No. 3, pp. 213-233.

8 Hill, L.D., J.P. Brophy, S. Zhang, and W. Florkowski. 1991. Farmer Attitudes Towards Technological Changes Affecting Grain Handling and Quality, Bulletin 805, University of Illinois at Urbana-Champaign, College of Agriculture, Agricultural Experiment Station.

9 Iowa Agricultural Statistics. 1991. Iowa Crop Report, press release of March 5, 1991, Iowa Agricultural Statistics, Des Moines, Iowa.

10 Iowa Department of Agriculture and Land Stewardship. 1991. Grain Marketing: Iowa, Iowa Department of Agriculture.

11 Lindeburg, M.R. 1988. Engineering Unit Conversions, Professional Publications Inc., Belmont, CA

12 Marland, G., and A. Turhollow. 1990. Carbon Dioxide Emissions from Production and Combustion of Fuel Ethanol from Corn, Oak Ridge National Laboratory, ORNL/TM-11180.

13 Parisi, Frederico. 1983. Energy Balances or Ethanol as a Fuel, Advances in Biochemical Engineering/Biotechnology, 28:42--68 (1983).

14 Pimentel, David (ed.). 1980. Handbook of Energy Utilization in Agriculture, CRC Press, Boca Raton, FL.

15 Pimentel, David et al. 1988. Food Versus Biomass Fuel: Socioeconomic and Environmental Impacts in the United States, Brazil, India, and Kenya, Advances in Food Research, Vol. 32, pp. 185-238, 1988.

16 United States Department of Agriculture, Office of Pesticide Research. 1987. Biologic and Economic Assessment of Stored Corn, Wheat, and Peanut Fumigants in The Biologic and Economic Assessment of Registered Fumigants, USDA Office of Pesticide Research, Washington, D.C.

17 United States Department of Agriculture, National Agricultural Statistics Service, Crop Production: 1994 Summary, Cr Pr 2-1(95), January 1995.

18 United States Department of Agriculture. 1994 (revised 1995). Summary Report: 1992 National Resources Inventory, USDA Natural Resources Conservation Service and the Iowa State University Statistical Laboratory.

19 United States Department of Energy, Energy Information Administration. 1994. Annual Energy Review: 1993, DOE/EIA-0384(93).

20 United States Department of Energy, Energy Information Administration. 1994. Emissions of Greenhouse Gases in the United States: 1987-1992, DOE/EIA-0573

21 United States Environmental Protection Agency. 1985. Compilation of Air Pollutant Emission Factors, AP-42 Fourth Edition.

22 United States Environmental Protection Agency. 1995. Compilation of Air Pollutant Emission Factors, AP-42 Fifth Edition.

23 United States Environmental Protection Agency. 1991. Nonroad Engine and Vehicle Emission Study-Appendixes (sp): Draft, 21A-2001 (NTIS #PB92-104462).

24 Unnasch, Stefan. 1990. Greenhouse Gas Emissions from Ethanol Production and Vehicle Use, Acurex Corp. for the National Corn Growers Association.

25 Weast, R.C., and M.J. Astle (ed). 1981. Handbook of Chemistry and Physics, 62nd Edition, CRC Press, Boca Raton, Florida.

26 Weinblatt, Herbert, T.S. Reddy, and Anthony Turhollow. 1982. Energy and Precious Fuels Requirements of Fuel Alcohol Production, Vol. II, Appendices A and B: Ethanol from Grain, DOE/NASA/0292-1

List of Tables



Summary Output:

| Allocated LCI components | | Units | Quantity | DQI | Notes: |
|---|---|---|---|---|---|
| Air | | | | | |
| | Particulates | lb/bu | 2.41E-01 | 3 | Dominated by grain handling, emission factor quality average. |
| | SOx | lb/bu | 4.33E-04 | 3 | Based on old emission factor data. |
| | CO | lb/bu | 2.37E-03 | 3 | Based on old emission factor data. |
| | CO2 | lb/bu | 4.70E-01 | 3 | Based on old emission factor data. |
| | Hydrocarbons | lb/bu | 1.03E-03 | 3 | Based on old emission factor data. |
| | NOx | lb/bu | 4.49E-03 | 3 | Based on old emission factor data. |
| | Aldehydes | lb/bu | 6.70E-05 | 3 | Based on old emission factor data. |
| | Organic Acids | lb/bu | 4.25E-05 | 3 | From train transport. Old data but quality rating good. |
| Water | | None | | | |
| Solid Wastes | | None | | | |
| Resource Use | Diesel | Btu/bu | 2,920 | 3 | Detailed estimate |

| | Table 6 Train Transport |
|---|---|
| Particulates | 1.52E-04 |
| SOx | 3.46E-04 |
| CO | 7.89E-04 |
| CO2 | 1.36E-01 |
| Hydrocarbons | 5.70E-04 |
| NOx | 2.24E-03 |
| Aldehydes | 3.34E-05 |
| Organic Acids | 4.25E-05 |

Conversion Factors

| Unit from | Unit to | Multiplier | Name | Source: | Notes: |
|---|---|---|---|---|---|
| Gallons Ethanol | Btu | 84,600 | btu_gallon | 5 | |
| Gallon Ethanol | lb | 6.58 | lb_gallon | 25 | Specific Gravity = .7893 |
| Gallon Ethanol | bu | 0.4 | bu_gallon | 6 | Depending on plant and process may range from .385 to .40. |
| Btu | Joules | 1,055 | Joules_btu | 11 | |
| kg | lb | 2.20 | lb_kg | 11 | |
| bu | lb | 56 | lb_bu | | |
| kcal | btu | 3.968 | btu_kcal | 11 | |
| sq. miles | acres | 640 | acres_sqmile | 11 | |
| short tons | lb | 2,000 | lb_shortton | 11 | |
| Barrels | gallons | 42 | gallons_barrel | 19 | |
| Gallon Gasoline | btu | 125,071 | btu_gallongas | 19 | |
| Gallon Diesel | btu | 138,690 | btu_gallondies | 19 | |
| Cubic Feet N.G. | btu | 1,031 | btu_cubicft | 19 | |

Molecular Wts.

| Element/Compound | Name | Wt. | Defined Name |
|---|---|---|---|
| C | Carbon | 12.01 | |
| O | Oxygen | 16.00 | |
| CO2 | Carbon Dioxide | 44.01 | |
| Ratio CO2:C | | 3.66 | carbon_ratio |

Calculations

---

Table 1 Energy Use in Transporation: Estimates as cited in DeLuchi (1993)

DeLuchi, M. 1993. Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity, Argonne National Laboratory, ANL/ESD/TM-22, Vol. 2.

| LCI component | Reference | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units | Transformed Quan. | Transformed Std. Dev. |
|---|---|---|---|---|---|---|---|---|
| Transporation Energy Use | Giampietro and Pimen | Btu/Btu-ethanol | 0.06 | | | Btu/bu | 12,690 | |
| | Chambers et al. (1979 | Btu/Btu-ethanol | 0.09 | | | Btu/bu | 19,035 | |
| | Parisi (1983) | Btu/Btu-ethanol | 0.1 | | | Btu/bu | 21,150 | |
| | Pimentel (1990) | Btu/Btu-ethanol | 0.07 | | | Btu/bu | 14,805 | |
| | DeLuchi (1993) | Btu/Btu-ethanol | 0.03 | | | Btu/bu | 6,345 | |

Notes: DeLuchi states in Table K-7 that all data are referenced to the higher heating value of ethanol, and gives transporattion energy consumption estimates as a function of btu/btu ethanol. I transform these estimates to btu/bu, then give the values as they appear in the actual reference for those references which I have, below.

Calculations

Table 2 Energy Use in Transporation Estimates

Parisi, Frederico. 1983. Energy Balances or Ethanol as a Fuel, Advances in Biochemical Engineering/Biotechnology, 28:42--68 (1983).

Pimentel, David et al. 1988. Food Versus Biomass Fuel: Socioeconomic and Environmental Impacts in the United States, Brazil, India, and Kenya, Advances in Food Research, Vol. 32, pp. 185-238, 1988.

Chambers, R.S., et al. 1979. Gasohol: Does It or Doesn't It Produce Positive Net Energy, Science, vol. 206, November 1979, pp. 789-795.

DeLuchi, M. 1993. Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity, Argonne National Laboratory, ANL/ESD/TM-22, Vol. 2.

Unnasch, Stefan. 1990. Greenhouse Gas Emissions from Ethanol Production and Vehicle Use, Acurex Corp. for the National Corn Growers Association.

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Transformed Units | Transformed Quan. | Notes: |
|---|---|---|---|---|---|
| Energy to Transport Corn to Mill | kcal/2700 kg | 325,000 | Btu/bu | 12,132 | Pimentel et al. (1988). Estimated as 10% of the |
| | Btu/bu | 21,000 | Btu/bu | 21,000 | Chambers et al. (1979) cites ACR (1978) (unp |
| | MJ/kg ethanol | 2.93 | Btu/bu | 20,727 | Parisi cites Chambers (1979) |
| | MJ/kg ethanol | 0.45 | Btu/bu | 3,183 | Parisi cites Scheller (1978) |
| | Btu/lb | 5,600 | Btu/bu | 5,600 | DeLuchi (1993) calculated based on truck tran |
| | Btu/bu | 4,000 | Btu/bu | 4,000 | Unnasch (1990) |
| | Average of Scheller, DeLuchi, Pimentel, Unnasch, and Chambers Estimates. | | | 9,183 | |
| | | | Standard Deviation | 7,484 | |

Notes: The variability in literature estimates of energy use in corn transportation is high. The value arrived at in the calculation below is also much smaller than these estimates 2,920 btu/lb. Since most of the above estimates were made using crude assumptions, this value is used.

Table 3 Iowa Corn Transportation Statistics

(1) Iowa Department of Agriculture and Land Stewardship. 1991. Grain Marketing: Iowa, Iowa Department of Agriculture.

(2) Baumel, C. Philip, Charles R. Hurburgh, and Tenpao Lee. 1985. Estimates of Total Fuel Consumption in Transporting Grain from Iowa to Major Grain Importing Countries by Alternative Modes and Routes: Special Report 90, Iowa Agricultural and Home Economics Experiment Station, Iowa University of Science and Technology, Ames, Iowa.

(3) Baumel, C. Philip, Stephen Baumhover, Michael A. Lipsman, and Marty J. McVey. 1991. Alternative Investments in the Rural Branch Railroad and County Road Systems, Midwest Transportation Center, Iowa State University, Ames, Iowa.

(4) Baumel, C. Philip, unpublished data, Iowa State University, Ames, Iowa.

Grain Merchandised by Elevators/Grain Dealers (1)
Domestic Processing

| | Method Shipped Truck | Rail | Barge | |
|---|---|---|---|---|
| Percent of Bushels | 38.1% | 61.7% | | 0.2% |
| Average Distance (miles) | 58 | 281 | ND | |

Grain Shipped by Farmers to Country Elevators (3)

| Vehicle Type | Percent | Average 1-way Distance |
|---|---|---|
| Semi tractor-trailor | 32% | 8 |
| Tandem axle truck | 29% | 13.5 |
| Single axle truck | 9% | 9.3 |
| Tractor - one wagon | 20% | 6.3 |
| Tractor - two wagons | 10% | 6.3 |

| | | |
|---|---|---|
| Grain Shipped Directly from Farm to Processor | | Source: |
| Percent of total grain processed | 20% | (4) |

| Vehicle Type | Percent | Average Distance | Notes: |
|---|---|---|---|
| Tandem Axle | 5% | 58 | Assumed to be the same as average distance from elevator to farmer |
| Semi | 95% | 58 | Assumed to be the same as average distance from elevator to farmer |

Notes: According to this model, 80% of corn processed domestically is shipped first to an elevator, then to the processor. The remaining 20% is shipped straight from farm to processor, which includes some corn sold to the elevator but transported directly to the processor.

---

Table 4 Energy Intensity of Corn Transportation Modes

(1) Baumel, C. Philip, Charles R. Hurburgh, and Tenpao Lee. 1985. Estimates of Total Fuel Consumption in Transporting Grain from Iowa to Major Grain Importing Countries by Alternative Modes and Routes: Special Report 90, Iowa Agricultural and Home Economics Experiment Station, Iowa University of Science and Technology, Ames, Iowa.

(2) Baumel, C. Philip, Stephen Baumhover, Michael A. Lipsman, and Marty J. McVey. 1991. Alternative Investments in the Rural Branch Railroad and County Road Systems, Midwest Transportation Center, Iowa State University, Ames, Iowa.

(3) Baumel, C. Philip, unpublished data, Iowa State University, Ames, Iowa.

Energy Intensity of Corn Transportation Modes

| Mode | Intensity | Units | Source: | Fuel | Transformed Intensity | Units | Capacity | Units | Capacity | Units |
|---|---|---|---|---|---|---|---|---|---|---|
| Rail | 640.1 | Net Ton-mi/gallon | (1) | Diesel | 22,861 | Net Bu-mi/gallon | | | | |
| Semi trucks | 90.5 | Net Ton-mi/gallon | (1) | Diesel | 3,232 | Net Bu-mi/gallon | 950 | bu | 53,200 | lb |
| Tandem axle trucks | 37.8 | Net Ton-mi/gallon | (2) | Diesel | 1,350 | Net Bu-mi/gallon | 600 | bu | 33,600 | lb |
| Single axle trucks | 30.2 | Net Ton-mi/gallon | (2) | Gasoline | 1,079 | Net Bu-mi/gallon | 300 | bu | 16,800 | lb |
| Tractor - 1-300 bushel wagon | 12.6 | Net Ton-mi/gallon | (3) | Diesel | 450 | Net Bu-mi/gallon | 300 | bu | 16,800 | lb |
| Tractor - 2-300 bushel wagons | 25.2 | Net Ton-mi/gallon | (3) | Diesel | 900 | Net Bu-mi/gallon | 600 | bu | 33,600 | lb |

Notes: Energy intensity estimates in terms of net ton-miles per gallon account for the actual tonnage hauled and the distance traveled unloaded (backhaul). Thus bushel-miles per gallon cannot be used to calculate a real mileage, since they include unloaded miles.

---

Table 5 Derived Total Transportation Requirements for Corn

From Table 3

| Mode | Distance (1-way) | Units | Energy | Units |
|---|---|---|---|---|
| Railroad | 138.70 | Miles | 841.5 | Btu/bu |
| Semi tractor-trailor | 28.70 | Miles | 1,231.4 | Btu/bu |
| Tandem axle truck | 3.71 | Miles | 381.3 | Btu/bu |
| Single axle truck | 0.67 | Miles | 77.6 | Btu/bu |
| Tractor - one wagon | 1.01 | Miles | 310.7 | Btu/bu |
| Tractor - two wagons | 0.50 | Miles | 77.7 | Btu/bu |
| Total | | | 2,920.2 | Btu/bu |

Notes: In this table, the transportation modes, distances, intensity, and fractions have been used to generate what could be called the average bushel transportation requirements. This does not imply that any single bushel actually travels the above distances for each mode. Instead it is a way

of representing the average requirements to transport corn.

---

Table 6 Emissions from Train Transport

(1) U.S. EPA, AP-42, Table II-2.1 (1985)

(2) U.S. DOE/EIA. 1994. Annual Energy Review: 1993, DOE/EIA-0384(93).

(3) DOE/EIA. 1994. Emissions of Greenhouse Gases in the United States: 1987-1992, DOE/EIA-0573

| Energy Intensity | | | |
|---|---|---|---|
| | 841 | Btu/bu | From Table Above |
| | 0.0061 | Gallons/bu | |

| Emission Factors - Railway | Raw Input Quantity | Units | Source | Transformed Quantity | Units |
|---|---|---|---|---|---|
| Particulates | 25 | lb/1000 gal fuel | (1) | 0.18 | lb/million btu |
| SOx | 57 | lb/1000 gal fuel | (1) | 0.41 | lb/million btu |
| CO | 130 | lb/1000 gal fuel | (1) | 0.94 | lb/million btu |
| CO2 | 19.95 | kg/million btu | (4) | 161.16 | lb/million btu |
| Hydrocarbons | 94 | lb/1000 gal fuel | (1) | 0.68 | lb/million btu |
| NOx | 370 | lb/1000 gal fuel | (1) | 2.67 | lb/million btu |
| Aldehydes | 5.5 | lb/1000 gal fuel | (1) | 0.04 | lb/million btu |
| Organic Acids | 7 | lb/1000 gal fuel | (1) | 0.05 | lb/million btu |

| Emissions | Quantity | Units |
|---|---|---|
| Particulates | 1.52E-04 | lb/bu |
| SOx | 3.46E-04 | lb/bu |
| CO | 7.89E-04 | lb/bu |
| CO2 | 1.36E-01 | lb/bu |
| Hydrocarbons | 5.70E-04 | lb/bu |
| NOx | 2.24E-03 | lb/bu |
| Aldehydes | 3.34E-05 | lb/bu |
| Organic Acids | 4.25E-05 | lb/bu |

---

Table 7 Emissions from Truck Transportation

(1) Davis, Stacy C. 1994. Transportation Energy Data Book: Edition 14, Oak Ridge National Laboratory, ORNL-6798.

(2) DeLuchi, M. 1993. Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity, Argonne National Laboratory, ANL/ESD/TM-22, Vol. 2.

(3) Blanchard, Paul H. 1992. Technology of Corn Wet Milling and Associated Processes, Industrial Chemical Library, vol. 4, Elsevier Press, New York.

(4) U.S. DOE/EIA. 1994. Annual Energy Review: 1993, DOE/EIA-0384(93).

(5) United States Environmental Protection Agency. 1985. Compilation of Air Pollutant Emission Factors, AP-42 Fourth Edition.

Estimated Transport Distance

| | Distance | Units | Energy | Units |
|---|---|---|---|---|
| Semi | 28.70 | Miles | 1,231.44 | Btu/bu |
| Tandem Axle | 3.71 | Miles | 381.35 | Btu/bu |
| Single Axle | 0.67 | Miles | 77.65 | Btu/bu |

Estimated Vehicle Load

| | | | Notes: |
|---|---|---|---|
| Semi | 53,200 | lb | Data provided by Philip Baumel |
| Tandem Axle | 33,600 | lb | Data provided by Philip Baumel |
| Single Axle | 16,800 | lb | Data provided by Philip Baumel |

Vehicle Registration Mix: January 1 & emissions factors , g/mile (5)

| | Gas Trucks | | | | Light Duty Diesel | | | | Heavy Diesel Trucks | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Model Year | Fraction | Total Hydro. | CO | NOx | Fraction | Total Hydro. | CO | NOx | Fraction | Total Hydro. | CO |
| Model Year - 1 | 0 | 2.8 | 12.6 | 4.4 | 0.008 | 0.3 | 1.2 | 0.9 | 0.031 | 2.4 | 7.9 |
| Model Year - 2 | 0.136 | 2.9 | 13.2 | 4.5 | 0.006 | 0.3 | 1.2 | 0.9 | 0.007 | 2.5 | 8.3 |
| Model Year - 3 | 0.116 | 3.1 | 14.6 | 4.8 | 0.008 | 0.4 | 1.2 | 0.9 | 0.008 | 2.6 | 9.1 |
| Model Year - 4 | 0.099 | 3.2 | 15.6 | 4.9 | 0.011 | 0.4 | 1.3 | 1 | 0.01 | 2.7 | 9.9 |
| Model Year - 5 | 0.085 | 3.4 | 16.5 | 5.1 | 0.017 | 0.4 | 1.3 | 1 | 0.012 | 2.8 | 10.5 |
| Model Year - 6 | 0.072 | 3.6 | 17.7 | 5.4 | 0.023 | 0.5 | 1.4 | 1 | 0.014 | 2.9 | 11.1 |
| Model Year - 7 | 0.062 | 3.7 | 18.4 | 5.5 | 0.029 | 0.5 | 1.4 | 1.1 | 0.017 | 3 | 11.6 |
| Model Year - 8 | 0.053 | 3.8 | 19.1 | 5.6 | 0.035 | 0.5 | 1.4 | 1.1 | 0.021 | 3.1 | 12.1 |
| Model Year - 9 | 0.045 | 3.9 | 19.7 | 5.7 | 0.041 | 0.5 | 1.5 | 1.1 | 0.025 | 3.2 | 12.5 |
| Model Year - 10 | 0.038 | 4.8 | 41.6 | 5.2 | 0.047 | 0.6 | 1.5 | 1.1 | 0.03 | 3.3 | 13.2 |
| Model Year - 11 | 0.033 | 5.2 | 50.2 | 5.2 | 0.053 | 0.6 | 1.5 | 1.2 | 0.036 | 4 | 13.7 |
| Model Year - 12 | 0.028 | 12.8 | 158.2 | 5.6 | 0.059 | 0.6 | 1.6 | 1.6 | 0.043 | 5.6 | 14.8 |
| Model Year - 13 | 0.024 | 13 | 160.4 | 5.6 | 0.065 | 0.6 | 1.6 | 1.6 | 0.051 | 5.7 | 15.1 |
| Model Year - 14 | 0.02 | 13.1 | 165.2 | 5.7 | 0.071 | 0.6 | 1.6 | 1.7 | 0.061 | 5.8 | 15.4 |
| Model Year - 15 | 0.018 | 13.2 | 167.8 | 5.7 | 0.077 | 0.7 | 1.7 | 1.7 | 0.073 | 6.7 | 16.9 |
| Model Year - 16 | 0.015 | 13.8 | 182.5 | 6.1 | 0.083 | 0.7 | 1.7 | 1.9 | 0.088 | 6.8 | 17.2 |
| Model Year - 17 | 0.013 | 13.9 | 184.8 | 6.1 | 0.089 | 1.4 | 2.4 | 1.9 | 0.105 | 7.3 | 20.2 |
| Model Year - 18 | 0.011 | 18.3 | 211.1 | 6.4 | 0.095 | 1.4 | 2.5 | 2 | 0.126 | 7.4 | 20.5 |
| Model Year - 19 | 0.009 | 19.8 | 241.3 | 7.3 | 0.101 | 1.5 | 2.5 | 2 | 0.151 | 7.5 | 20.7 |
| Model Year - 20 | 0.045 | 19.9 | 243.3 | 7.4 | 0.027 | 1.5 | 2.5 | 2 | 0 | 7.5 | 20.9 |
| Weighted Average | 92.20% | 5.9 | 53.3 | 5.3 | 94.50% | 0.5 | 1.4 | 1.1 | 90.90% | 3.7 | 12.1 |

| Emission Factors | | Raw Input Quantity | Units | Transformed Input Quantity | Units |
|---|---|---|---|---|---|
| Gas Truck | Hydrocarbons | 5.9 | g/mile | 0.0129 | lb/mi |
| | Carbon Monoxide | 53.3 | g/mile | 0.1176 | lb/mi |
| | NOx | 5.3 | g/mile | 0.0117 | lb/mi |
| Light Diesel Truck | Hydrocarbons | 0.5 | g/mile | 0.0012 | lb/mi |
| | Carbon Monoxide | 1.4 | g/mile | 0.0031 | lb/mi |
| | NOx | 1.1 | g/mile | 0.0025 | lb/mi |
| Heavy Diesel Truck | Hydrocarbons | 3.7 | g/mile | 0.0081 | lb/mi |
| | Carbon Monoxide | 12.1 | g/mile | 0.0267 | lb/mi |
| | NOx | 14.6 | g/mile | 0.0322 | lb/mi |
| CO2 Emission Factors | Gas | 19.4 | kg/million btu | 156.79 | lb/million btu |
| | Diesel | 20.0 | kg/million btu | 161.16 | lb/million btu |

| Emissions | | Heavy Diesel | Light Diesel | Gas | Total | Units |
|---|---|---|---|---|---|---|
| | Hydrocarbons | 0.00024 | 7.22087E-06 | 2.88839E-05 | 0.000279415 | lb/bu |
| | Carbon Monoxide | 0.00081 | 1.9375E-05 | 0.000262436 | 0.00108736 | lb/bu |
| | NOx | 0.00097 | 1.54607E-05 | 2.60841E-05 | 0.001014646 | lb/bu |
| | CO2 | 0.19845 | 0.061456568 | 0.012174601 | 0.2720858 | lb/bu |

Notes: The three categories of trucks used in corn transportation were arbitrarily assigned to the three categories of trucks for which emissions factors are available in AP-42. There is some danger in this since the AP-42 emission factors are given in terms of g/mi. Clearly the size assumptions about the truck categories in AP-42 would have a significant impact on the emission factors in terms of grams/mi. Closer examination of AP-42 reveals that the light truck category refers to vehicles with gross weights between 6,000 and 8,500 lbs. This suggests that the BMI load estimate of 10,000 lb is high. Unfortunately the resolution of the AP-42 data is poor. The category large trucks includes all vehicles over 8,500 lbs. Thus, while the large vehicle capacity of 42,000 lb is confirmed as being reasonable fo trucks used to haul corn, this would seem to fall at the high end of the large truck category in AP-42. Lacking more detailed truck emission factors, these estimates will be used.

---

Table 8 Emissions from Tractor Transport

(1) U.S. EPA. 1991. Nonroad Engine and Vehicle Emission Study-Appendixes (sp): Draft, 21A-2001 (NTIS #PB92-104462).

(2) United States Department of Energy, Energy Information Administration. 1994. Emissions of Greenhouse Gases in the United States: 1987-1992, DOE/EIA-0573

Estimated Energy Usage

| | Energy | Units | Fuel | Units |
|---|---|---|---|---|
| Tractor - one wagon | 311 | btu/bu | 0.00224 | Gallons/bu |
| Tractor - two wagons | 78 | btu/bu | 0.00056 | Gallons/bu |

| | | | | | |
|---|---|---|---|---|---|
| Total | 388 | btu/bu | 0.0028 | Gallons/bu | |

| Farm Equipment Emission Factors | Units | Raw Input Quantity HC | CO | NOx | SOx | Particulate | Aldehydes | Source | Notes |
|---|---|---|---|---|---|---|---|---|---|
| Diesel Tractors | lb/1000 gallons | 63.55 | 175 | 438.59 | 31.2 | 45.7 | 12 | (1) | Weighted by factors for large 2WD, small 2WD, and 4WD tractors. |

| Carbon Dioxide Emission Factor | Quantity | Units | Source |
|---|---|---|---|
| Diesel | 19.95 | kg/million btu | (2) |
| | 161.16 | lb/million btu | |

Emissions

| | Quantity | Units |
|---|---|---|
| Hydrocarbons | 1.78E-04 | lb/bu |
| CO | 4.90E-04 | lb/bu |
| NOx | 1.23E-03 | lb/bu |
| SOx | 8.74E-05 | lb/bu |
| Particulate | 1.28E-04 | lb/bu |
| Aldehydes | 3.36E-05 | lb/bu |
| $CO_2$ | 0.06 | lb/bu |

Notes: In this table, emission factors for diesel tractors have been used for all tractor transport. While on farm energy consumption estimates suggest that some gasoline is used, it is not possible to determine the amount of gasoline used in tractors. Since some transport is carried out by light trucks, and since some of these trucks may be gas powered, it is assumed here that assigning diesel emission factors to tractor transport is a reasonable approximation. The impact of this assumption is primarily on the carbon monoxide estimates, for which gas tractors have an extremely high emission factor. Lacking additional data, the diesel tractor assumption will be used.

---

Table 9 Fumigant and Grain Protectant Use in Grain Storage

Personal Communication, C.L. Storey, Consultant on Protection of Stored Grains, July 27, 1995.

United States Department of Agriculture, Office of Pesticide Research. 1987. Biologic and Economic Assessment of Stored Corn, Wheat, and Peanut Fumigants in The Biologic and Economic Assessment of Registered Fumigants, USDA Office of Pesticide Research, Washington, D.C.

Aluminum Phosphide Use: 1987

| Off Farm | Total Use | Units | Corn Treated | Units | Use Rate | Units |
|---|---|---|---|---|---|---|
| | 20,790 | kg | 415.8 | million Bushels | 1.10E-04 | lb/bu |

Percent of Corn Bushels Treated
20.7%

Aluminum Phosphide use per Total Bushels
2.28E-05 lb/bu

For many reasons, the use of chemicals to protect stored grain is negligible. Corn carries a lenient standard relative to grains such as wheat, on the number of insects allowed per unit measure before the grain is classified as weevily. About 65-70% of corn also never leaves the region in which it was produced, which limits storage and transportation times, again limiting the need for chemical treatment. Finally, the use of chemical protectants is very small relative to the use of insecticides and herbicides applied in the field.

Though several different types of fumigants were once used with corn, many of these have not been re-registered by the EPA. These include Methyl Bromide, which is an ozone depleting substance, and well as chloropicrin and magnesium phosphide. The only fumigant currently in use in significant quantities is aluminum phosphide. This substance produces a phosphine gas which is toxic to both insects and humans, and is suspected of causing genetic abnormalities in cell tissue. Charles Storey estimates that less than 10% of corn is fumigated.
Of grain protectants, actelic (parimifos methyl) is the only important one used on corn. Again, the use of this substance is estimated to be very small.

---

Table 10 Particulate Emissions from Uncontrolled Grain Elevators

U.S. EPA. 1985. AP-42 Compilation of Air Pollutant Emission Factors,4th Edition
Chapter 6.4-1.

| Emission Factors | Process | Quantity | Units |
|---|---|---|---|
| Country Elevators | Unloading | 0.6 | lb/ton |

| | | | | | |
|---|---|---|---|---|---|
| | Loading | 0.4 | lb/ton | | |
| | Removal From Bins | 2 | lb/ton | | |
| | Drying | 0.2 | lb/ton | | |
| | Cleaning | 0.4 | lb/ton | | |
| | Headhouse | 5 | lb/ton | Tranformed Quantity | Units |
| | Total | 8.6 | lb/ton | 0.2408 | lb/bu |
| Inland Terminal Elevators | Unloading | 1 | lb/ton | | |
| | Loading | 0.4 | lb/ton | | |
| | Removal From Bins | 2.8 | lb/ton | | |
| | Drying | 0.2 | lb/ton | | |
| | Cleaning | 0.6 | lb/ton | | |
| | Headhouse | 4.6 | lb/ton | | |
| | Tripper (Gallery Belt) | 1.6 | lb/ton | | |
| | Total | 11.2 | lb/ton | | |
| | | | | Tranformed Quantity | Units |
| Average | | 9.9 | lb/ton | 0.2772 | lb/bu |

Notes: These emission factors account for the quantity of grain processed by each operation per unit of grain shipped. This ranges from as low as 0.1 to as high as 3.1. These data indicate that about 30% of grain received at country elevators is dried at the elevator, compared to 10% of received grain being dried at at inland terminal elevators. Since corn bound for domestic processing usually passes only through country elevators, the emission factors for country elevators are used. It is assumed that all energy use for drying is accounted for in the corn production sheet.

EOF

| Table 7 Truck Transport | Table 8 Tractor Transport | Table 12 Grain Handling | Total |
|---|---|---|---|
| - | 1.28E-04 | 2.41E-01 | 0.24108 |
| - | 8.74E-05 | - | 0.000433 |
| 1.09E-03 | 4.90E-04 | - | 0.002366 |
| 2.72E-01 | 6.26E-02 | - | 0.470276 |
| 2.79E-04 | 1.78E-04 | - | 0.001028 |
| 1.01E-03 | 1.23E-03 | - | 0.004488 |
| - | 3.36E-05 | - | 6.7E-05 |
| - | - | - | 4.25E-05 |

| | Table 6 Train Transport | Table 7 Truck Transport | Table 8 Tractor Transport | Table 12 Grain Handling | Total |
|---|---|---|---|---|---|
| Particulates | 0% | #VALUE! | 0% | 100% | 100% |
| SOx | 80% | #VALUE! | 20% | #VALUE! | 100% |
| CO | 33% | 46% | 21% | #VALUE! | 100% |
| CO2 | 29% | 58% | 13% | #VALUE! | 100% |
| Hydrocarbons | 55% | 27% | 17% | #VALUE! | 100% |
| NOx | 50% | 23% | 27% | #VALUE! | 100% |
| Aldehydes | 50% | #VALUE! | 50% | #VALUE! | 100% |
| Organic Acids | 100% | #VALUE! | #VALUE! | #VALUE! | 100% |

e energy input to corn production, including energy in fertilizers, etc.
ublished).

sport 80 miles roundtrip plus occaisional train transport bringing total energy to 200,000 Btu/ton.

| Transformed Intensity | Units |
|---|---|
| 6.1 | Btu/Bu-mile |
| 42.9 | Btu/Bu-mile |
| 102.7 | Btu/Bu-mile |
| 116.0 | Btu/Bu-mile |
| 308.2 | Btu/Bu-mile |
| 154.1 | Btu/Bu-mile |

Product of weighting times emission factor

| NOx | Model Year | Gas Trucks: Total Hydro. | Gas Trucks: CO | Gas Trucks: NOx | Light Duty Diesel: Fraction | Light Duty Diesel: Total Hydro. | Light Duty Diesel: CO | Light Duty Diesel: NOx | Heavy Diesel Trucks: Fraction | Heavy Diesel Trucks: Total Hydro | Heavy Diesel Trucks: CO | Heavy Diesel Trucks: NOx |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 | Model Year -1 | 0 | 0 | 0 | | 0 | 0 | 0 | | 0 | 0 | 0 |
| 11.1 | Model Year - 2 | 0.3944 | 1.7952 | 0.612 | | 0.0408 | 0.1632 | 0.1224 | | 0.34 | 1.1288 | 1.5096 |
| 11.5 | Model Year - 3 | 0.3596 | 1.6936 | 0.5568 | | 0.0464 | 0.1392 | 0.1044 | | 0.3016 | 1.0556 | 1.334 |
| 12 | Model Year - 4 | 0.3168 | 1.5444 | 0.4851 | | 0.0396 | 0.1287 | 0.099 | | 0.2673 | 0.9801 | 1.188 |
| 12.2 | Model Year - 5 | 0.289 | 1.4025 | 0.4335 | | 0.034 | 0.1105 | 0.085 | | 0.238 | 0.8925 | 1.037 |
| 12.5 | Model Year - 6 | 0.2592 | 1.2744 | 0.3888 | | 0.036 | 0.1008 | 0.072 | | 0.2088 | 0.7992 | 0.9 |
| 12.7 | Model Year - 7 | 0.2294 | 1.1408 | 0.341 | | 0.031 | 0.0868 | 0.0682 | | 0.186 | 0.7192 | 0.7874 |
| 12.9 | Model Year - 8 | 0.2014 | 1.0123 | 0.2968 | | 0.0265 | 0.0742 | 0.0583 | | 0.1643 | 0.6413 | 0.6837 |
| 13.1 | Model Year - 9 | 0.1755 | 0.8865 | 0.2565 | | 0.0225 | 0.0675 | 0.0495 | | 0.144 | 0.5625 | 0.5895 |
| 17.9 | Model Year - 10 | 0.1824 | 1.5808 | 0.1976 | | 0.0228 | 0.057 | 0.0418 | | 0.1254 | 0.5016 | 0.6802 |
| 18.2 | Model Year - 11 | 0.1716 | 1.6566 | 0.1716 | | 0.0198 | 0.0495 | 0.0396 | | 0.132 | 0.4521 | 0.6006 |
| 18.9 | Model Year - 12 | 0.3584 | 4.4296 | 0.1568 | | 0.0168 | 0.0448 | 0.0448 | | 0.1568 | 0.4144 | 0.5292 |
| 18.9 | Model Year - 13 | 0.312 | 3.8496 | 0.1344 | | 0.0144 | 0.0384 | 0.0384 | | 0.1368 | 0.3624 | 0.4536 |
| 18.9 | Model Year - 14 | 0.262 | 3.304 | 0.114 | | 0.012 | 0.032 | 0.034 | | 0.116 | 0.308 | 0.378 |
| 20.5 | Model Year - 15 | 0.2376 | 3.0204 | 0.1026 | | 0.0126 | 0.0306 | 0.0306 | | 0.1206 | 0.3042 | 0.369 |
| 20.5 | Model Year - 16 | 0.207 | 2.7375 | 0.0915 | | 0.0105 | 0.0255 | 0.0285 | | 0.102 | 0.258 | 0.3075 |
| 24.8 | Model Year - 17 | 0.1807 | 2.4024 | 0.0793 | | 0.0182 | 0.0312 | 0.0247 | | 0.0949 | 0.2626 | 0.3224 |
| 24.8 | Model Year - 18 | 0.2013 | 2.3221 | 0.0704 | | 0.0154 | 0.0275 | 0.022 | | 0.0814 | 0.2255 | 0.2728 |
| 24.8 | Model Year - 19 | 0.1782 | 2.1717 | 0.0657 | | 0.0135 | 0.0225 | 0.018 | | 0.0675 | 0.1863 | 0.2232 |
| 24.8 | Model Year - 20 | 0.8955 | 10.9485 | 0.333 | | 0.0675 | 0.1125 | 0.09 | | 0.3375 | 0.9405 | 1.116 |
| 14.6 | sum | 5.412 | 49.1729 | 4.8874 | | 0.5003 | 1.3424 | 1.0712 | | 3.3209 | 10.9948 | 13.2817 |

Sheet Title: Corn Wet Milling Last Modified 10/04/95

Sheet Description:

This sheet contains an inventory of the wet corn milling process. The process inputs and outputs are normalized to one bushel of corn input. Energy intensity estimates for wet corn milling are derived from 1991 MECS data for SIC 2046. This industry includes manufacturers of wheat, potato, and tapioca starch, as well as corn starch and other corn wet milling products. Though the industry has relatively high coverage (.95) and specialization (.88) ratios (U.S. Department of Commerce 1994), the industry does produce significant quantities of ethanol, a relatively energy intensive product. Most public literature on material consumption by the industry separates out materials used for ethanol production. Energy use estimates contained in MECS do not make this distinction, however. In order to use the MECS data it is necessary to allocate some fraction of energy consumption to the production of potato, wheat, and tapioca starch, as well as ethanol production. The first two tables in this sheet deal with the allocation of energy consumption to these products. Table 3 then uses the adjusted MECS data to develop an energy balance for the wet corn milling industry.

There are also several co-products of glucose (or corn starch, depending on the desired end product). These include corn oil, and animal feeds. Inputs and outputs of the industry must be allocated between these products. This has been done on this sheet on the basis of product dry weight. Thus the right hand column gives the inputs and outputs per pound of product output, which can be applied to any of the products and coproducts.

Some data was derived in these estimates from publicly available databases. Because these datasets are fairly large, they have been included on separate sheets of the file. Sheet two contains the raw TRI data. Sheet three contains power plant coal ash content data. Sheet 4 contains power plant sulfur content data.

NREL has developed a process model for a wet corn mill to provide glucose for the BDO process. The starch conversion component of this model was only recently completed, and so while the results are often included here for comparison purposes, insufficient time was available to reconcile differences. Some of these are fairly significant. For example energy use in the NREL model is only about half that estimated based on public data. The estimates based on public data are crude enough to suggest that this discrepancy may be an overestimate. Again, the time frame for completion of the module limit our ability to further explore the source of these differences.

References/citations:


1 Austin, George T. 1984. Shreve's Chemical Process Industries, fifth edition, McGraw Hill, New York.

2 Babcock and Wilcox. 1992. Steam: Its Generation and Use, 40th Edition, S.C. Stulz and J.B. Kitto (eds.).

3 Blanchard, Paul H. 1992. Technology of Corn Wet Milling and Associated Processes, Industrial Chemical Library, vol. 4, Elsevier Press, New York.

4 Boynton, Robert S. 1980. Chemistry and Technology of Lime and Limestone, Second Edition, John Wiley and Sons, Inc., New York.

5 CE Power Systems. 1967. Steam Tables: Properties of Saturated and Superheated Steam, reprinted from ASME Steam Tables (1967).

6 Cengel, Y. A., and M. Boles. 1989. Thermodynamics: An Engineering Approach, McGraw-Hill, Inc., New York.

7 Chambers, R.S., et al. 1979. Gasohol: Does It or Doesn't It Produce Positive Net Energy, Science, vol. 206, November 1979, pp. 789-795.

8 Code of Federal Regulations, 40 CFR 406.15, 1994 edition.

9 Corn Refiners Association, Inc. 1994?. 1994 Corn Annual, Corn Refiners Association, Washington, D.C.

10 Davis, Stacy C. 1994. Transportation Energy Data Book: Edition 14, Oak Ridge National Laboratory, ORNL-6798.

11 DeLuchi, M. 1993. Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity,

Argonne National Laboratory, ANL/ESD/TM-22, Vol. 2.

12 Divine, T.E., D.P. Alzheimer, and W.F. Smith. 1977. Estimates of Process Energy Use in Four Key Food Products Industries, presented at the 1977 Annual Meeting of the Pacific Northwest Region American Society of Agricultural Engineers, Pendelton, OR, September 7-9, 1977.

13 Giampietro, M., and David Pimentel. 1990. Alcohol and Biogass Production from Biomass, Critical Reviews in Plant Sciences, Vol. 9, No. 3, pp. 213-233.

14 Jones, K.W. 1989. Operation Case Histories of the South Point Ethanol and Kentucky Agricultural Energy Corporation Fuel Ethanol Plants in, Energy from Biomass and Wastes XII, D.L. Klass (ed.), Institute of Gas Technology, pp. 1343-1375.

15 Lindeburg, M.R. 1988. Engineering Unit Conversions, Professional Publications Inc., Belmont, CA

16 Marland, G., and A. Turhollow. 1990. Carbon Dioxide Emissions from Production and Combustion of Fuel Ethanol from Corn, Oak Ridge National Laboratory, ORNL/TM-11180.

17 Murray, B.C., D.H. Gross, and T.J. Fox. 1994. Starch Manufacturing: A Profile, Final report to the U.S. EPA by the Center for Economics and Research, Research Triangle Park, NC.

18 National Corn Growers Association, and National Corn Development Foundation. 1995. The World of Corn: 1995.

19 Parisi, Frederico. 1983. Energy Balances or Ethanol as a Fuel, Advances in Biochemical Engineering/Biotechnology, 28:42--68 (1983).

20 Pimentel, David (ed.). 1980. Handbook of Energy Utilization in Agriculture, CRC Press, Boca Raton, FL.

21 Pimentel, David et al. 1988. Food Versus Biomass Fuel: Socioeconomic and Environmental Impacts in the United States, Brazil, India, and Kenya, Advances in Food Research, Vol. 32, pp. 185-238, 1988.

22 United States Department of Agriculture, Economic Research Service. 1993. Feed Situation and Outlook Report.

23 USDA/ERS. 1994. Sugar and Sweetner: Situation and Outlook Report, SSSV 19N2, June 1994.

24 U.S. Department of Commerce, Bureau of the Census. 1994. 1992 Census of Manufactures: Grain Mill Products, MC92-I-20D(P).

25 United States Department of Energy, Energy Information Administration. 1994. Manufacturing Consumption of Energy: 1991, DOE/EIA 0512(91).

26 United States Department of Energy, Energy Information Administration. 1994. Emissions of Greenhouse Gases in the U.S.: 1987-1992, DOE/EIA-0573.

27 United States Department of Energy, Energy Information Administration. 1993. Annual Energy Review: 1993, DOE/EIA-0384(93).

28 United States Environmental Protection Agency. 1995. Compilation of Air Pollutant Emission Factors, AP-42 Fifth Edition.

29 U.S. EPA. 1980. Source Category Survey: Starch Manufacturing Industry, EPA-450/3-80-040

30 U.S. EPA. 1981. Source Category Survey: Animal Feed Dryers, EPA-450/3-81-017

31 United States Department of the Interior, Bureau of Mines. 1994. Mineral Commodity Summaries: 1994

32 Unnasch, Stefan. 1990. Greenhouse Gas Emission from Ethanol Production and Vehicle Use, Acurex Corp. for the Nat'l Corn Growers Association

33 Utility Data Institute. 1995. EEI Power Statistics Database.

34 Weast, R.C., and M.J. Astle (ed). 1981. Handbook of Chemistry and Physics, 62nd Edition, CRC Press, Boca Raton, Florida.

35 Weinblatt, Herbert, T.S. Reddy, and Anthonly Turhollow. 1982. Energy and Precious Fuels Requirements of Fuel Alcohol Production, Vol. II, Appendices A and B: Ethanol from Grain, DOE/NASA/0292-1

36 Whistler, R. L., J.N. BeMiller, and E.F. Paschall (ed.). 1984. Starch: Chemistry and Technology, Academic Press, NY.

List of Tables:



Summary Output:

| Allocated LCI components | | Units | Unallocated Quantity | Units | Allocated Quantity | Data Quality Indicator | Comments |
|---|---|---|---|---|---|---|---|
| Air | NOx | lb/bu | 0.048 | lb/lb product | 9.72E-04 | 2 | Driven by AP-42 data on fluidized bed coal combustion, data qu |
| | SOx | lb/bu | 0.052 | lb/lb product | 1.06E-03 | 2 | Driven by AP-42 data on fluidized bed coal combustion, data qu |
| | PM-10 | lb/bu | 0.032 | lb/lb product | 6.41E-04 | 2 | Driven by AP-42 data on fluidized bed coal combustion, data qu |
| | Total Particulate | lb/bu | 0.086 | lb/lb product | 1.74E-03 | 2 | Large variations in uncontrolled and controlled values. |
| | CO | lb/bu | 0.044 | lb/lb product | 8.91E-04 | 2 | Driven by AP-42 data on fluidized bed coal combustion, data qu |
| | CO2 | lb/bu | 15.62 | lb/lb product | 3.18E-01 | 2 | Driven by AP-42 data on fluidized bed coal combustion, data qu |
| | Non-Methane Org. Com | lb/bu | 1.73E-04 | lb/lb product | 3.51E-06 | 2 | Driven by AP-42 data on fluidized bed coal combustion, data qu |
| | Methane | lb/bu | 1.52E-04 | lb/lb product | 3.09E-06 | 2 | Driven by AP-42 data on fluidized bed coal combustion, data qu |
| | N2O | lb/bu | 0.013 | lb/lb product | 2.72E-04 | 2 | Driven by AP-42 data on fluidized bed coal combustion, data qu |
| | HCL | lb/bu | 3.57E-04 | lb/lb product | 7.26E-06 | 3 | Based on aggregate TRI data for several years. |
| | Ammonia | lb/bu | 8.85E-05 | lb/lb product | 1.80E-06 | 3 | Based on aggregate TRI data for several years. |
| | Chlorine | lb/bu | 3.91E-05 | lb/lb product | 7.95E-07 | 3 | Based on aggregate TRI data for several years. |
| | Sulfuric Acid | lb/bu | 2.41E-05 | lb/lb product | 4.90E-07 | 3 | Based on aggregate TRI data for several years. |
| Water | Total Water Emission | gallons/bu | 30 | gallons/lb product | 0.61 | 3 | Typical estimate. No assessment of statistical reliability. |
| | Ammonia | lb/bu | 2.80E-04 | lb/lb product | 5.70E-06 | 3 | Based on aggregate TRI data for several years. |
| | Chlorine | lb/bu | 1.60E-06 | lb/lb product | 3.26E-08 | 3 | Based on aggregate TRI data for several years. |
| | BOD5 | lb/bu | 0.020 | lb/lb product | 4.07E-04 | 3 | Based on CFR regulations for new Facilitites. |
| | TSS | lb/bu | 0.025 | lb/lb product | 5.09E-04 | 3 | Based on CFR regulations for new Facilitites. |
| Solid Wastes | HCL | lb/bu | 5.50E-06 | lb/lb product | 1.12E-07 | 3 | Based on aggregate TRI data for several years. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Ammonia | lb/bu | 9.00E-06 | lb/lb product | 1.83E-07 | 3 | Based on aggregate TRI data for several years. |
| | Coal Ash | lb/bu | 0.64 | lb/lb product | 1.30E-02 | 3 | Estimated from information on typical mid-west utility coal. |
| Resource Cons | N.G. | Btu/bu | 40,479 | Btu/lb product | 823 | 2 | No current process specific data available. Derived from industr |
| | Coal | Btu/bu | 52,255 | Btu/lb product | 1,063 | 2 | No current process specific data available. Derived from industr |
| | Electricity | Kwh/bu | 3.38 | Kwh/lb product | 0.069 | 2 | No current process specific data available. Derived from industr |
| | Water | gallons/bu | 35 | Gallons/lb product | 0.712 | 2 | Typical estimate. No assessment of statistical reliability. |
| | Sulfur | lb/bu | 0.06 | lb/lb product | 0.0012 | 3 | Modeled estimate conforms with other published estimates. |
| Outputs | Total | lb/bu | 49.16 | Percent | 100.00% | 4 | Material balance based on large sample and current data, and c |
| | Glucose | lb/bu | 32.17 | Percent | 65.45% | 4 | Material balance based on large sample and current data, and c |
| | Corn Oil | lb/bu | 0.95 | Percent | 1.94% | 4 | Material balance based on large sample and current data, and c |
| | Gluten Feed | lb/bu | 13.60 | Percent | 27.67% | 4 | Material balance based on large sample and current data, and c |
| | Gluten Meal | lb/bu | 2.43 | Percent | 4.94% | 4 | Material balance based on large sample and current data, and c |

Conversion Factors

| Unit from | Unit to | Multiplier | Name | Source | |
|---|---|---|---|---|---|
| bu | lb | 56 | lb_bu | | |
| Hectares | acre | 2.47 | acre_ha | 15 | |
| kg | lb | 2.20 | lb_kg | 15 | |
| hectares | sq. meters | 10,000 | sqmeters_ha | 15 | |
| meter | feet | 3.28 | feet_meter | 15 | |
| short tons | lb | 2,000 | lb_shortton | 15 | |
| kcal | btu | 3.97 | btu_kcal | 15 | |
| Joules | btu | 9.47E-04 | btu_joule | 15 | |
| Gallons Ethano | lb | 6.58 | lb_gallon | 34 | Specific Gravity = .7893 |
| Gallons Ethano | bu | 0.4 | bu_gallon | 11 | Depending on plant and process may range from .385 to .40. |
| Hectares | Sq. cm | 1.00E+08 | sqcm_ha | 15 | |
| cubic cm | liters | 0.001 | liters_ccm | 15 | |
| liters | gallons | 0.264 | gallons_liter | 15 | |
| sq mile | acres | 640 | acres_sqmile | 15 | |
| metric tons | short tons | 1.10 | shortton_metricton | 15 | |
| Gallon Ethanol | Btu | 84,600 | Btu_gallon | 10 | |
| Gallons | liters | 3.7854 | liters_gallon | 15 | |
| Gallons water | lb | 8.35 | lb_gallonw | 15 | |
| Tons of Coal | Million Btu | 22,276,000 | btu_toncoal | 25 | |

| Molecular Wts. | Element/Compound | Name | Wt. | Defined Name |
|---|---|---|---|---|
| | Ca | Calcium | 40.080 | |
| | O | Oxygen | 15.999 | |
| | S | Sulfur | 32.060 | |
| | CaSO4 | Calcium Sulfate | 96.058 | |
| | C | Carbon | 12.011 | |

| | | | |
|---|---|---|---|
| CO2 | Carbon Dioxide | 44.010 | |
| Ratio CaSO4:S | | 4.246 | gypsum_ratio |
| Ratio CO2:Ca | | 1.098 | calcium_ratio |
| Ratio CO2:S | | 1.373 | sulfur_ratio |
| Ratio CO2:C | | 3.66 | carbon_ratio |
| Ratio S:SO2 | | 0.50 | sulfoxide_ratio |

Calculatio ----------------------------------------------------------------------------------------------------

Table 1 Ethanol Production: 1991


(1) USDA/ERS.1993. Feed Situation and Outloook Report.

(2) National Corn Growers Association, and National Corn Development Foundation. 1995. The World of Corn: 1995.

(3) Data provided by Kathy Bryan, Consultant to Ethanol Industry

(4) Marland, G., and A. Turhollow. 1990. Carbon Dioxide Emissions from Production and Combustion of Fuel Ethanol from Corn, Oak Ridge National Laboratory, ORNL/TM-11180.

(5) DeLuchi, M. 1993. Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity, Argonne National Laboratory, ANL/ESD/TM-22, Vol. 2.

(6) Unnasch, Stefan. 1990. Greenhouse Gas Emission from Ethanol Production and Vehicle Use, Acurex Corp. for the Nat'l Corn Growers Association

(7) Weinblatt, Herbert, T.S. Reddy, and Anthonly Turhollow. 1982. Energy and Precious Fuels Requirements of Fuel Alcohol Production, Vol. II, Appendices A and B: Ethanol from Grain, DOE/NASA/0292-1

(9) Jones, K.W. 1989. Operation Case Histories of the South Point Ethanol and Kentucky Agricultural Energy Corporation Fuel Ethanol Plants in, Energy from Biomass and Wastes XII, D.L. Klass (ed.), Institute of Gas Technology, pp. 1343-1375.


| | Raw Input Quantity | Units | Source | | |
|---|---|---|---|---|---|
| Corn Grind for A | 429 | Million Bu | (1) | | |
| Ethanol per bu | 2.5 | Gallons/bu | (2) | | |
| Gallons Ethano | 1072.5 | Million Gallons | (calculated) | | |
| % Capacity of C | 49.70% | | (3) | | |
| Estimated Prod | 533 | Million Gallons | (calculated) | | |
| Energy Intensity | 49,504 | Btu/gallon | (see below) | 49504 | Btu/gallon |
| | 1.36 | Kwh/gallon | (see below) | 4637 | Btu/gallon |
| Energy Consum | 26.39 | Trillion Btu | (calculated) | 26.39 | Trillion Btu |
| | 724 | Million Kwh | (calculated) | 2.47 | Trillion Btu |

Notes: Corn use data is typically based on the corn marketing year, which, like the DOE fiscal year, begins September 1. I have used the 1990/91

marketing year data to estimate corn grind for alcohol production in 1991.

Estimates of Energy Intensity of Ethanol Production

| Raw Input Quantity | Units | Source | Range from | to | Transformed Input Quantity | Units | Range from | to | Units |
|---|---|---|---|---|---|---|---|---|---|
| 17.11 | MM J/kg | (4) | 14.11 | 20.11 | 48,366 | Btu/gallon | 39,885 | 56,846 | Btu/gallon |
| 0.32 | kwh/liter | | | | 4,133 | Btu/gallon | | | |
| 0.525 | Btu/Btu Ethanol | (5) | 0.35 | 0.6 | 44,415 | Btu/gallon | 29,610 | 50,760 | Btu/gallon |
| 0.05 | Btu/Btu Ethanol | (electricity) | | | 4,230 | Btu/gallon | | | |
| 41,000 | Btu/gal | (6) | 34,000 | 48,000 | 41,000 | Btu/gallon | 34,000 | 48,000 | Btu/gallon |
| 1.50 | kwh/gallon | | | | 5,118 | Btu/gallon | | | |
| 0.55 | Btu/Btu Ethanol | (7) | | | 46,530 | Btu/gallon | | | |
| 1.26 | kwh/gallon | | | | 4,299 | Btu/gallon | Notes: | | |
| 16,329 | tons coal | (9) | | | 67,351 | Btu/gallon | South Point Ethanol in October 1984 | | |
| 7,236,232 | kwh | | | | 4,572 | Btu/gallon | | | |
| 5,400,744 | gallons ethanol | | | | | | | | |
| 4,670 | tons coal | (9) | | | 49,361 | Btu/gallon | Kentucky Ag. Energy plant in July 1987 | | |
| 3,378,600 | kwh | | | | 5,470 | Btu/gallon | | | |
| 2,107,511 | gallons ethanol | | | | | | | | |
| | | | | Average | 49,504 | Btu/gallon | Fuel | | |
| | | | | | 4,637 | Btu/gallon | Electricity | | |
| | | | | | 1.36 | kwh/gallon | Electricity | | |

Notes: Ethanol energy intensity estimates vary more widely than is indicated by this data. I have tried to use the most recent data available for which both fuel and electricity estimates are given separately. Where possible I have used electricity estimates given in kwh/unit ethanol to avoid errors in converting to btus. I then convert to btus using the convention of 3412 btu/kwh.

---

Table 2 Production of Potato and Wheat Starch in SIC 2046


(1) CE Power Systems. 1967. Steam Tables: Properties of Saturated and Superheated Steam, reprinted from ASME Steam Tables (1967).

(2) Cengel, Y. A., and M. Boles. 1989. Thermodynamics: An Engineering Approach, McGraw-Hill, Inc., New York.

(3) Murray, B.C., D.H. Gross, and T.J. Fox. 1994. Starch Manufacturing: A Profile, Final report to the U.S. EPA by the Center for Economics and Research, Research Triangle Park, NC.

(4) Personal Communication, Damon Horn, A.E. Staley, Stanfield, OR.
Personal Communication, Mick Persinger, Penwest, Richland, WA.

Most potato starch plants purchase a slurry from other processing facilitities (e.g. A.E. Staley, Stanfield and Murtaugh plants, and Penwest, Richland and Idaho Falls plants). Energy is consumed in motors and dryers. Assuming that the drying energy dominates, we can calculate an energy intensity per lb based on data from A.E. Staley, Stanfield.

| | | Raw Input Quantity | Units | Source | Notes: |
|---|---|---|---|---|---|
| Purchased Slurry | | | | | |
| Slurry Density | | 22 | Baume | (4) | Damon Horn provided me with detailed estimates of the operating parameters of a mill which dries purchases s |
| Approximate Solids | | 36% | | (4) | |
| Centrifuge to | | | | | |
| Cake Moisture | | 42.00% | | (4) | |
| Dry to | | | | | |
| Final Moisture | | 12.50% | | (4) | |
| Dryer Operation | | | | | |
| Input | Water | 63,362 | lb/day | (calculated) | |
| | Starch | 87,500 | lb/day | (calculated) | |
| | Total | 150,862 | lb/day | (calculated) | |
| Output | Water | 12,500 | lb/day | (calculated) | |
| | Starch | 87,500 | lb/day | (calculated) | |
| | Total | 100,000 | lb/day | (4) | |
| Dryer RemovesWater | | 50,862 | lb/day | (calculated) | |
| Enthalpy of Vaporization at 212 F | | 970.30 | Btu/lb | (1) | |
| Specific Heat of Water | | 1 | Btu/F | (2) | |
| Temp in | | 70 | F | (estimate) | |
| Temp out | | 212 | F | (estimate) | |
| Energy to dry starch | | 1,112 | Btu/lb water evaporate | (calculated) | |
| Total Energy | | 56,573,879 | Btu | (calculated) | |
| Intensity | | 566 | Btu/lb dry starch | (calculated) | |
| Dryer Rating | | 7 | million Btu/hr | (4) | This estimate was carried out as a check on the other method. While 90% efficinecy |
| Capacity | | 60% | | (4) | may be a little high for a starch dryer, for the level of accuracy needed here |
| Effective Input | | 4.2 | million Btu/hr | (calculated) | this provides and acceptable concurrence to the above energy intensity estimate. |
| Daily Operation | | 15 | hours | (4) | |
| Output | | 100,000 | lb | (4) | |
| Total Energy/lb | | 630 | Btu/lb | (calculated) | |
| Efficiency | | 89.8% | | (calculated) | |
| Potato Starch Production 1992 | | | | | |
| | | 0.207 | Billion lb | (3) | |
| Energy Use | | | | | |

| | | |
|---|---|---|
| | 1.30E+11 Btu | (calculated) |
| | 0.130 T Btu | (calculated) |

Estimate Wheat Starch Energy Intensity from Potato

None of the wheat starch mfgs would give me any info on energy. Ken Smick at ADM did say that they dry wheat starch from 35-40% solids down to 12% moisture content.

| | | |
|---|---|---|
| Wheat Starch Production 1992 | | |
| | 0.276 Billion lb | (3) |
| Energy Use | | |
| | 1.74E+11 Btu | (calculated) |
| | 0.174 T Btu | (calculated) |
| Same for Tapioca | | |
| Tapioca Starch Production 1992 | | |
| | 0.069 Billion lb | (3) |
| Energy Use | | |
| | 4.35E+10 Btu | (calculated) |
| | 0.043 T Btu | (calculated) |
| Total Potato, Wheat, and Tapioca Starch Energy | | |
| | 0.348 T Btu | (calculated) |

Notes: Based on these estimates the total energy use for starch drying is quite small. Assuming that there is additional electrical energy consumption, and that some facilities produce potato starch from potatoes instead of a slurry, the total energy consumption may be as much as double this value, which is still negligible relative to total energy use in SIC 2046.

---

Table 3 Wet Corn Mill Energy Balance

(1) Energy Information Administration. 1994. Manufacturing Consumption of Energy: 1991, DOE/EIA 0512(91).

(2) USDA/ERS. 1994. Sugar and Sweetner: Situation and Outlook Report, SSSV 19N2, June 1994.

(3) Divine, T.E., D.P. Alzheimer, and W.F. Smith. 1977. Estimates of Process Energy Use in Four Key Food Products Industries, presented at the 1977 Annual Meeting of the Pacific Northwest Region American Society of Agricultural Engineers, Pendelton, OR, September 7-9, 1977.

Notes: Based on 1991 MECS energy consumption for all purposes. Electricity data is taken from Table 4. Energy use is rounded to eliminate minor fuels, then adjusted to account for energy use in ethanol production.

1991 Corn Grin 811 MM Bu (2)

Total Primary Consumption of Fuel for All Purposes (MECS Table 1)
(Trillion Btu)

| Fuel | Raw Input Quantity | Rounded Input Quantity | Less Ethanol Energy | Adj. Total | Energy per Bushel (Btu) |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| R. Oil | 0.18 | 0 | 0 | 0 | 0 |
| D. Oil | 0.17 | 0 | 0 | 0 | 0 |
| N.G. | 52 | 55 | 12 | 43 | 53,615 |
| LPG | 0.004 | 0 | 0 | 0 | 0 |
| Coal | 68 | 71 | 15 | 56 | 69,212 |
| Coke, Breeze and Other | 6 | 0 | 0 | 0 | 0 |
| Electricity | | | | | |
| Purchased | 14 | 14 | 2 | 12 | 15,293 |
| Sold | 0 | 0 | 0 | 0 | 0 |
| Conv. Gen. | 6 | 6 | 1 | 5 | 6,519 |
| Renew. Gen. | 0 | 0 | 0 | 0 | 0 |
| Net Fuel | 126 | 126 | 26 | 100 | 122,827 |
| Net Electric | 20 | 20 | 2 | 18 | 21,812 |

Energy Intensity of Production - SIC 2046

| | | | | |
|---|---|---|---|---|
| Energy Consumed | 100 | Tbtu | | |
| Grind | 811 | MM bushels | | |
| Fuel Energy Intensity | 122,827 | Btu/bu | 2,193 | Btu/lb |
| Electric Energy Intensity | 15,293 | Btu/bu | 4.48 | Kwh/lb |
| Fraction of energy used for starch processing and syrup concentra | 24.5% | (3) | | |
| Fuel Intensity of Glucose Production | 92,735 | Btu/bu | 1,656 | Btu/lb |
| Electric Intensity of Glucose Production | 11,547 | Btu/bu | 0.06 | Kwh/lb |

Notes: Significant processing of starch and glucose products (such as glucose concentration or starch modification) occurs in wet corn mills.
To try and account for the most energy intensive aspects of this processing, the fraction of energy used for these processes from reference 7
has been deducted from the total wet mill energy intensity estimate. While this is a rather crude method, lacking additional data it will have to suffice.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Fuel Split | | | | | | | | | | |
| Natural Gas | | 40,479 | Btu/bu | | 40,479 | Btu/bu | 723 | Btu/lb | | 43.65% |
| Coal | | 52,255 | Btu/bu | | 52,255 | Btu/bu | 933 | Btu/lb | | 56.35% |
| Electricty | Purchased | 11,547 | Btu/bu | | 3.38 | Kwh/bu | 6.04E-02 | Kwh/lb | | |
| | Generated | 1,597 | Btu/bu | | 0.47 | Kwh/bu | 8.36E-03 | Kwh/lb | | |
| Other EstimatesTotal | | 4,100 | Btu/lb | (3) | | | 229,600 | Btu/bu | | |
| Less Syrup Concentration, starch drying, and dextr | | 3,096 | Btu/lb | (3) | | | 173,376 | Btu/bu | | |

| | kg steam | kg corn | lb steam/lb corn | lb steam/bu | Btu/bu | Btu/lb |
|---|---|---|---|---|---|---|
| NREL Estimate | 507,182,742 | 579,078,355 | 0.88 | 49.05 | 44,658 | 797 |

Assuming 80% efficiency boilers total fu 997

| | Electricity Use (kwh/yr) | Starch Use (kg/yr) | Corn Use to Produce S | Energy Intensity (kwh/kg | Energy Intensity (kwh/lb corn) |
|---|---|---|---|---|---|
| NREL Electricit | 2,524,789 | 110,225,570 | 184,690,076 | 0.014 | 0.030 |

Because the NREL data has only recently been provided, and is still in the process of being updated, it was not possible to resolve the differences in estimates.

Notes: Based on this estimate the energy intensity of wet corn milling has dropped significantly since 1977. This seems fairly reasonable in such a long time frame. It can also be compared to the energy intensity estimate for ethano 2,417 Btu/lb. This suggests that our estimate is at least in the ballpark for corn processing at wet mills.

Table 4 Electricity Balance in Wet Corn Milling Industry

Electricity Balance. Raw Input Data from MECS Tables 4, 16, 17. All data in million Kwh.
Estimated values (mine) are in bold type. Calculated values are in italics.
Tranfers in are assumed to equal zero. Thus purchases equal the sum of purchases and transfers in. Sales can be calculated for the Midwest and U.S. regions as the difference between columns E and K. Next, conventional generation can be calculated for the Midwest and U.S. regions from columns J - C + I. Finally conventional generation in the West and South must be estimated. If the ratio of generation to purchases is assumed to be the same in these two regions, successive guesses can be made until the relationship is balanced. Using 15 million kwh conv. generation in the West, the remaining values can be calculated, giving a reasonable balance to the table.

| Region | Table 4 Purchases | Transfers In | Table 4 P&T in | Table 16 Gen. (conv.) | Table 17 Gen. (renew.) | E + F Total Onsite Gen. | Table 16 Sales and Transfers | Table 16 P&Tin + Gen - Sale Net Demand | Table 4 P&Tin + Renew. - Sale Net Electricity |
|---|---|---|---|---|---|---|---|---|---|
| West | 93 | 0 | 93 | 15 | 0 | 15 | 0 | 108 | 93 |
| South | 837 | 0 | 837 | 134 | 0 | 134 | 82 | 889 | 755 |
| Midwest | 3,199 | 0 | 3,199 | 1,617 | 0 | 1,617 | 7 | 4,809 | 3,192 |
| Northeast | 15 | 0 | 15 | 0 | 0 | 0 | 0 | 15 | 15 |
| U.S. | 4,143 | 0 | 4,143 | 1,766 | 0 | 1,766 | 89 | 5,820 | 4,054 |
| U.S. (Quads) | 14.14 | 0.00 | 14.14 | 6.03 | 0.00 | 6.03 | 0.30 | 19.86 | 13.83 |

| ratio generation to purchases | | Balance Net Demand |
|---|---|---|
| West | 0.161 | 1 |
| South | 0.160 | |

Table 5 Emissions from Energy Consumption In Wet Corn Mills


(1) U.S. EPA, AP-42, Sections 1.1 and 1.4

(2) Personal Communication, Bob Bessette, Council of Industrial Boilers, 6-16-95.

(3) United States Department of Energy, Energy Information Administration. 1993. Annual Energy Review: 1993, DOE/EIA-0384(93).

(4) United States Department of Energy, Energy Information Administration. 1994. Emissions of Greenhouse Gases in the U.S.: 1987-1992, DOE/EIA-0573.

(5) Utility Data Institute. 1995. EEI Power Statistics Database.

| Emission Facto | Fuel | Pollutant | Category | Raw Input Quantity | Units | Source | Notes | Transformed Input Quantity |
|---|---|---|---|---|---|---|---|---|
| | Gas | | | | | | | |
| | | NOx | | | | | | |
| | | | Uncontrolled | 550 | lb/million cubic feet | (1) | | 0.53346 |
| | | | Low NOx | 81 | lb/million cubic feet | (1) | | 0.07856 |
| | | | Flue Gas Recirc. | 53 | lb/million cubic feet | (1) | | 0.05141 |
| | | NOx | Average | 308.5 | lb/million cubic feet | | | 0.29922 |
| | | SO2 | | 0.6 | lb/million cubic feet | (1) | | 0.00058 |
| | | PM-10 | | 13.7 | lb/million cubic feet | (1) | Data are for small industrial boilers. | 0.01329 |
| | | CO | | 40 | lb/million cubic feet | (1) | Uncontrolled emission factor. No data fo | 0.03880 |
| | | CO2 | | 14.47 | million m tons carbon/Q | (4) | Data are for small industrial boilers | 116.88885 |
| | | Non-Methane VOC's | | 1.411 | lb/million cubic feet | (1) | | 0.00137 |
| | | Methane | | 0.289 | lb/million cubic feet | (1) | | 0.00028 |
| | | N2O | | 0 | lb/million cubic feet | (1) | | |
| | Coal Heat Content | | | 22.276 | Million btu/ton | (3) | | |
| | Coal | | | | | | | |
| | | NOx | | 15.2 | lb/ton | (1) | | 0.68235 |
| | | SO2 | | 22.1 | lb/ton | (1) | | 0.99356 |
| | | PM-10 | | 13.2 | lb/ton | (1) | | 0.59257 |
| | | CO | | 18 | lb/ton | (1) | | 0.80804 |
| | | CO2 | | 25.58 | million m tons carbon/Q | (4) | | 206.63558 |
| | | Non-Methane VOC's | | 0.05 | lb/ton | (1) | | 0.00224 |
| | | Methane | | 0.06 | lb/ton | (1) | | 0.00269 |
| | | N2O | | 5.7 | lb/ton | (1) | Average of values for bubbling and circu | 0.25588 |

SO2 emission factor estimate for fluidized bed coal boilers

SO2 emissions can be calculated as SO2 = 39.6*S*(Ca/S)^-1.9 where S is the sulfur percentage of the coal, and Ca/S is the calcium to sulfur ratio in the bed.

| | | | |
|---|---|---|---|
| Ca/S | 2.2 | (ratio) | (2) |
| Sulfur percent | 2.50 | percent | (estimate) |
| SO2 | 22.1 | lb/ton | (calculated) |
| | 0.99 | lb/mm btu | (calculated) |

| Fuel Related En | Quantity | Units |
|---|---|---|
| NOx | 0.04777 | lb/bu |
| SO2 | 0.05194 | lb/bu |
| PM-10 | 0.03150 | lb/bu |

| | | |
|---|---|---|
| CO | 0.04380 | lb/bu |
| CO2 | 15.52937 | lb/bu |
| Non-Methane V | 0.00017 | lb/bu |
| Methane | 0.00015 | lb/bu |
| N2O | 0.01337 | lb/bu |

Notes: According to Bob Bessett, fluidized bed boilers are the most common type used in this industry. Emissions from coal are thus estimated based on emission factors for this technology. Because fluidized bed boilers remove sulfur, it is possible to burn much higher sulfur content coal without surpassing limits on sulfur emissions. For utilitites in Iowa, Illinois and Indiana, the average sulfur content of coal used was around 1.5% in 1993 (5). I assume a sulfur content of 2.50 percent to account for the use of cheap, high sulfur coal in FBC boilers.

---

Table 6 Toxic Releases from The Wet Corn Milling Industry

(1) U.S. EPA, Toxic Release Inventory, Data downloaded from Right To Know (RTK) Network online database.
(Raw data on sheet TOXICS)

(2) USDA/ERS.1993. Feed Situation and Outloook Report.

This Table includes data only on emissions of four toxics. For information on why other toxics categories were exluded, see the sheet TOXICS.

Total Toxic Releases of Ammonia, HCL, Chlorine, and Sulfuric Acid
All releases in lb

| Year | Grind (million bu) | Ammonia Fug Air | Stack Air | Water | Land |
|---|---|---|---|---|---|
| 1987 | 1104 | 416,721 | 1,000 | 50,250 | 50,459 |
| 1988 | 1160 | 68,669 | 3,686 | 161,420 | 250 |
| 1989 | 1221 | 81,151 | 5,052 | 710,368 | 1,450 |
| 1990 | 1221 | 19,706 | 8,332 | 776,472 | 6,865 |
| 1991 | 1318 | 18,264 | 5,384 | 427,024 | 13,576 |
| 1992 | 1375 | 16,252 | 4,437 | 266,877 | 0 |
| 1993 | 1413 | 71,687 | 1,725 | 56,649 | 0 |
| Total | | 692,450 | 29,616 | 2,449,060 | 72,600 |

Total Toxic Releases of Ammonia, HCL, Chlorine, and Sulfuric Acid
All releases in lb

| Year | Grind (million bu) | HCL Fug Air | Stack Air | Water | Land |
|---|---|---|---|---|---|
| 1987 | 1104 | 16,578 | 20,996 | 0 | 4,750 |
| 1988 | 1160 | 11,331 | 7,870 | 0 | 750 |
| 1989 | 1221 | 16,055 | 32,073 | 11 | 1,011 |
| 1990 | 1221 | 14,241 | 34,203 | 5 | 1,000 |
| 1991 | 1318 | 12,987 | 1,261,725 | 600 | 27,000 |
| 1992 | 1375 | 7,214 | 955,691 | 250 | 200 |
| 1993 | 1413 | 12,010 | 977,391 | 0 | 15,910 |
| Total | | 90,416 | 3,289,949 | 866 | 50,621 |

Total Toxic Releases of Ammonia, HCL, Chlorine, and Sulfuric Acid
All releases in lb

Chlorine

| Year | Grind (million bu) | Fug Air | Stack Air | Water | Land |
|---|---|---|---|---|---|
| 1987 | 1104 | 1,500 | 0 | 250 | 0 |
| 1988 | 1160 | 3,670 | 10,252 | 250 | 0 |
| 1989 | 1221 | 7,172 | 12,000 | 250 | 0 |
| 1990 | 1221 | 2,755 | 10 | 1,277 | 0 |
| 1991 | 1318 | 2,501 | 159,896 | 11,176 | 0 |
| 1992 | 1375 | 1,267 | 155,055 | 1,433 | 0 |
| 1993 | 1413 | 2,487 | 4,887 | 1 | 1 |
| Total | | 21,352 | 342,100 | 14,637 | 1 |

Total Toxic Releases of Ammonia, HCL, Chlorine, and Sulfuric Acid
All releases in lb

Sulfuric Acid

| Year | Grind (million bu) | Fug Air | Stack Air | Water | Land |
|---|---|---|---|---|---|
| 1987 | 1104 | 1,002 | 538 | 13 | 0 |
| 1988 | 1160 | 1,751 | 1,013 | 0 | 0 |
| 1989 | 1221 | 1,504 | 791 | 0 | 0 |
| 1990 | 1221 | 1,032 | 59 | 755 | 0 |
| 1991 | 1318 | 268 | 61 | 0 | 0 |
| 1992 | 1375 | 272 | 104,443 | 0 | 0 |
| 1993 | 1413 | 532 | 120,459 | 5 | 1,182 |
| Total | | 6,361 | 227,364 | 773 | 1,182 |

Toxic Releases per Bushel Corn Grind
Emissions Intensity (lb/bu)

Ammonia

| Year | Grind (million bu) | Fug Air | Stack Air | Water | Land |
|---|---|---|---|---|---|
| 1987 | 1104 | 3.77E-04 | 9.06E-07 | 4.55E-05 | 4.57E-05 |
| 1988 | 1160 | 5.92E-05 | 3.18E-06 | 1.39E-04 | 2.16E-07 |
| 1989 | 1221 | 6.65E-05 | 4.14E-06 | 5.82E-04 | 1.19E-06 |
| 1990 | 1221 | 1.61E-05 | 6.82E-06 | 6.36E-04 | 5.62E-06 |
| 1991 | 1318 | 1.39E-05 | 4.08E-06 | 3.24E-04 | 1.03E-05 |
| 1992 | 1375 | 1.18E-05 | 3.23E-06 | 1.94E-04 | 0 |
| 1993 | 1413 | 5.07E-05 | 1.22E-06 | 4.01E-05 | 0 |
| Average | | 8.51E-05 | 3.37E-06 | 2.80E-04 | 9.00E-06 |

Toxic Releases per Bushel Corn Grind
Emissions Intensity (lb/bu)

HCL

| Year | Grind (million bu) | Fug Air | Stack Air | Water | Land |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| 1987 | 1104 | 1.50E-05 | 1.90E-05 | 0 | 4.30E-06 |
| 1988 | 1160 | 9.77E-06 | 6.78E-06 | 0 | 6.47E-07 |
| 1989 | 1221 | 1.31E-05 | 2.63E-05 | 9.01E-09 | 8.28E-07 |
| 1990 | 1221 | 1.17E-05 | 2.80E-05 | 4.10E-09 | 8.19E-07 |
| 1991 | 1318 | 9.85E-06 | 9.57E-04 | 4.55E-07 | 2.05E-05 |
| 1992 | 1375 | 5.25E-06 | 6.95E-04 | 1.82E-07 | 1.45E-07 |
| 1993 | 1413 | 8.50E-06 | 6.92E-04 | 0 | 1.13E-05 |
| Average | | 1.05E-05 | 3.46E-04 | 9.29E-08 | 5.50E-06 |

Toxic Releases per Bushel Corn Grind
Emissions Intensity (lb/bu)

| Year | Grind (million bu) | Chlorine Fug Air | Stack Air | Water | Land |
|---|---|---|---|---|---|
| 1987 | 1104 | 1.36E-06 | 0.00E+00 | 2.26E-07 | 0 |
| 1988 | 1160 | 3.16E-06 | 8.84E-06 | 2.16E-07 | 0 |
| 1989 | 1221 | 5.87E-06 | 9.83E-06 | 2.05E-07 | 0 |
| 1990 | 1221 | 2.26E-06 | 8.19E-09 | 1.05E-06 | 0 |
| 1991 | 1318 | 1.90E-06 | 1.21E-04 | 8.48E-06 | 0 |
| 1992 | 1375 | 9.21E-07 | 1.13E-04 | 1.04E-06 | 0 |
| 1993 | 1413 | 1.76E-06 | 3.46E-06 | 7.08E-10 | 7.08E-10 |
| Average | | 2.46E-06 | 3.66E-05 | 1.60E-06 | 1.01E-10 |

Toxic Releases per Bushel Corn Grind
Emissions Intensity (lb/bu)

| Year | Grind (million bu) | Sulfuric Acid Fug Air | Stack Air | Water | Land |
|---|---|---|---|---|---|
| 1987 | 1104 | 9.08E-07 | 4.87E-07 | 1.18E-08 | 0 |
| 1988 | 1160 | 1.51E-06 | 8.73E-07 | 0 | 0 |
| 1989 | 1221 | 1.23E-06 | 6.48E-07 | 0 | 0 |
| 1990 | 1221 | 8.45E-07 | 4.83E-08 | 6.18E-07 | 0 |
| 1991 | 1318 | 2.03E-07 | 4.63E-08 | 0 | 0 |
| 1992 | 1375 | 1.98E-07 | 7.60E-05 | 0 | 0 |
| 1993 | 1413 | 3.77E-07 | 8.53E-05 | 3.54E-09 | 8.37E-07 |
| Average | | 7.53E-07 | 2.33E-05 | 9.05E-08 | 1.20E-07 |

Notes: for some emission pathways and pollutants the quantities are very small, and may be the result of a single emission from a single plant in a particular year. The resulting emission intensity thus becomes rather low. I have reset these values to zero since they represent outliers, and since the impact at such low levels of emission would be neglibible. These include land emissions of chlorine, sulfuric acid, and HCL, and water emissions of HCL and sulfuric acid. Some of the remaining emissions may still be of negligible quantity.

---

Table 7 Particulate Emissions from Corn Milling Operations

(1) U.S. EPA, AP-42, Table 6.4-6.

(2) U.S. EPA. 1980. Source Category Survey: Starch Manufacturing Industry, EPA-450/3-80-040

(3) U.S. EPA. 1981. Source Category Survey: Animal Feed Dryers, EPA-450/3-81-017

(4) Grogan, P.J., and D. J. Santini. 1981. Overview of Environmental Problems in the Food Industry, in Proceedings of the 36th Industrial Waste Conference, May 12-14, 1981, Lafayette, IN.

(5) U.S. EPA, AP-42, Table 9.9.7-1.

| Process Operation | | Emission Factor | Units | Source | Notes | Transformed Quantity | Units | Notes: |
|---|---|---|---|---|---|---|---|---|
| Receiving | Uncontrolled | 1 | lb/ton | (1) | | 0.02800 | lb/bushel corn | Converted based on the lb of corn per bush |
| Handling | Uncontrolled | 5 | lb/ton | (1) | | 0.14000 | lb/bushel corn | Converted based on the lb of corn per bush |
| Cleaning | Uncontrolled | 6 | lb/ton | (1) | | 0.16800 | lb/bushel corn | Converted based on the lb of corn per bush |
| Drying | Uncontrolled | 0.48 | lb/ton | (1) | | 0.01344 | lb/bushel corn | Drying of Corn. Thus this factor is converte |
| Bulk Loading | | | | | | | | |
| Grain Receiving | Fabric Filter | 0.033 | lb/ton | (5) | | 0.00092 | lb/bushel corn | Converted based on the lb of corn per bush |
| Grain Handling | Uncontrolled | 0.87 | lb/ton | (5) | | 0.02436 | lb/bushel corn | Converted based on the lb of corn per bush |
| Grain Cleaning | Uncontrolled | 1.6 | lb/ton | (5) | | 0.04480 | lb/bushel corn | Converted based on the lb of corn per bush |
| Grain Cleaning | Cyclone | 0.17 | lb/ton | (5) | | 0.00476 | lb/bushel corn | Converted based on the lb of corn per bush |
| Gluten Feed Dr | Direct-Rotary w/cyclone | 0.27 | lb/ton | (5) | | 0.00184 | lb/bushel corn | Converted based on the fraction of feed pro |
| Gluten Feed Dr | Indirect-Rotary w/cyclon | 0.49 | lb/ton | (5) | | 0.00333 | lb/bushel corn | Converted based on the fraction of feed pro |
| Gluten Drying | Direct-Rotary w/cyclone | 0.27 | lb/ton | (5) | | 0.00033 | lb/bushel corn | Converted based on the fraction of feed pro |
| Gluten Drying | Indirect-Rotary w/cyclon | 0.49 | lb/ton | (5) | | 0.00059 | lb/bushel corn | Converted based on the fraction of feed pro |
| Animal Feed Dr | Controlled | 0.71 | lb/ton | (2) | Gives a range of value | 0.00483 | lb/bushel corn | Converted based on the fraction of feed pro |
| | Controlled | 2.6 | lb/ton | (2) | | 0.01768 | lb/bushel corn | Converted based on the fraction of feed pro |
| | Uncontrolled | 14.2 | lb/ton | (2) | Based on assumed co | 0.09658 | lb/bushel corn | Converted based on the fraction of feed pro |
| | Uncontrolled | 52 | lb/ton | (2) | of 95%/ | 0.35366 | lb/bushel corn | Converted based on the fraction of feed pro |
| Handling | Controlled | 0.02 | lb/ton | (2) | | 0.00056 | lb/bushel corn | Converted based on the lb of corn per bush |
| | Uncontrolled | 0.41 | lb/ton | (2) | Based on assumed co of 95%/ | 0.01148 | lb/bushel corn | Converted based on the lb of corn per bush |
| Animal Feed Dryers (from plant level test data) | | | | | | | | |
| | Controlled | 0.71 | lb/ton | (2) | These are a series of p | 0.00483 | lb/bushel corn | Converted based on the fraction of feed pro |
| | | 2.6 | lb/ton | (2) | level data reported for | 0.01768 | lb/bushel corn | Converted based on the fraction of feed pro |
| | | 1 | lb/ton | (2) | dryer types. Clearly the | 0.00680 | lb/bushel corn | Converted based on the fraction of feed pro |
| | | 0.005 | lb/ton | (2) | above for controlled em | 0.00003 | lb/bushel corn | Converted based on the fraction of feed pro |
| | | 0.97 | lb/ton | (2) | came from here. | 0.00660 | lb/bushel corn | Converted based on the fraction of feed pro |
| | | 10.4 | lb/ton | (2) | | 0.07073 | lb/bushel corn | Converted based on the fraction of feed pro |
| | Mean | 2.61 | lb/ton | (2) | | 0.01778 | lb/bushel corn | Converted based on the fraction of feed pro |
| | Median | 0.985 | lb/ton | (2) | | 0.00670 | lb/bushel corn | Converted based on the fraction of feed pro |

Animal Feed Dryers

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| (from test and pControlled | 0.3 lb/ton | (3) | There is clearly someth | 0.00204 | lb/bushel corn | Converted based on the fraction of feed pro |
| Controlled | 0.7 lb/ton | (3) | this data. Not only are | 0.00476 | lb/bushel corn | Converted based on the fraction of feed pro |
| | | | lower than controlled factors, but the | | | |
| Uncontrolled | 0.2 lb/ton | (3) | average recommended | 0.00136 | lb/bushel corn | Converted based on the fraction of feed pro |
| Uncontrolled | 1 lb/ton | (3) | than the range of test a | 0.00680 | lb/bushel corn | Converted based on the fraction of feed pro |
| | | | values. | | | |
| Uncontrolled | 10 lb/ton | (3) | | 0.06801 | lb/bushel corn | Converted based on the fraction of feed pro |
| Total Particulate Emissions | 1.3 lb/ton | (4) | Range of values | 0.03640 | lb/bushel corn | Converted based on the lb of corn per bush |
| | 17.9 lb/ton | (4) | | 0.50120 | lb/bushel corn | Converted based on the lb of corn per bush |

Emission Values Used

| | | | | | |
|---|---|---|---|---|---|
| Receiving | 0.5165 lb/ton | Average of controlled and uncontrolled values. | 0.01446 | lb/bushel corn | Converted based on the lb of corn per bush |
| Handling | 0.33 lb/ton | Average of controlled values averaged with unco | 0.00924 | lb/bushel corn | Converted based on the lb of corn per bush |
| Cleaning | 0.885 lb/ton | Average of controlled and uncontrolled values. | 0.02478 | lb/bushel corn | Converted based on the lb of corn per bush |
| Drying | 0.845 lb/ton | Average of controlled values. This may understa | 0.00575 | lb/bushel corn | Converted based on the fraction of feed pro |
| Total | | emissions significantly. | 0.05423 | lb/bushel corn | |

Notes: for most emission categories the difference between controlled and uncontrolled is not too dramatic. Thus the lack of data on the prevalence of controls is not a serious problem. For drying, however, the range of values is quite large, or aboutf two orders of magnitude. Clearly the assumption about how to estimate the prevalance of controls on feed dryers is important. I used the average of 6 controlled values, assuming controls are common.

---

Table 8 Water Emissions from the Wet Corn Milling Industry


(1) Grogan, P.J., and D. J. Santini. 1981. Overview of Environmental Problems in the Food Industry, in Proceedings of the 36th Industrial Waste Conference, May 12-14, 1981, Lafayette, IN.

(2) Blanchard, Paul H. 1992. Technology of Corn Wet Milling and Associated Processes, Industrial Chemical Library, vol. 4, Elsevier Press, New York.

(3) Code of Federal Regulations, 40 CFR 406.15, 1994 edition.


| | | Raw Input Quantity | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Water | | Low | High | Average | Units | Source | Notes | Transformed Quantity |
| | Quantity | | 0.75 | 10 | 4.4 gallons/ton | (1) | Based on early 1970's data | 0.1232 |
| | BOD5 | | 4.2 | 25 | 14.8 lb/ton | (1) | Based on early 1970's data | 0.4144 |
| | TSS | | 1 | 19.6 | 7.5 lb/ton | (1) | Based on early 1970's data | 0.21 |
| Water | Quantity | | 25 | 35 | 30 gallons/bu | (2) | | 30 |
| | BOD5 | | 1000 | 3000 | 2000 ppm | (2) | before treatment | 0.5007 |
| | TSS | | | | 500 ppm | (2) | | 0.028 |
| EPA Limits | BOD5 | | | | 20 lb/k bu | (3) | Standards of performance for | 0.02 |
| (30 day average | TSS | | | | 25 lb/k bu | (3) | new sources, after treatment | 0.025 |

| | | | | |
|---|---|---|---|---|
| pH | 6.0 | 9.0 | | (3) |

Table 9 Water Consumption in Wet Corn Mills

(1) Blanchard, Paul H. 1992. Technology of Corn Wet Milling and Associated Processes, Industrial Chemical Library, vol. 4, Elsevier Press, New York.

(2) NREL Model

| Water Use | | Raw Input Quanitity | Units | Source: | Transformed Quantity | Units | Notes: |
|---|---|---|---|---|---|---|---|
| | | 30-40 | Gallons/bu | (1) | 35 | Gallons/bu | Average of estimated range |
| | Process | 1.43 | kg water/kg corn | (2) | 10 | Gallons/bu | |
| | Cooling Tower | 16.58 | kg water/kg corn | (2) | 111 | Gallons/bu | |

Table 10 Material Balance in Wet Corn Mills

(1) Corn Refiners Association, Inc. 1994?. 1994 Corn Annual, Corn Refiners Association, Washington, D.C.

(2) Murray, B.C., D.H. Gross, and T.J. Fox. 1994. Starch Manufacturing: A Profile, Final report to the U.S. EPA by the Center for Economics and Research, Research Triangle Park, NC.

(3) USDA/ERS. 1994. Sugar and Sweetner: Situation and Outlook Report, SSSV 19N2, June 1994.

(4) U.S. Department of Commerce, Bureau of the Census. 1994. 1992 Census of Manufactures: Grain Mill Products, MC92-I-20D(P).

(5) Whistler, R. L., J.N. BeMiller, and E.F. Paschall (ed.). 1984. Starch: Chemistry and Technology, Academic Press, NY.

(6) National Corn Growers Association, and National Corn Development Foundation. 1995. The World of Corn: 1995.

(7) Blanchard, Paul H. 1992. Technology of Corn Wet Milling and Associated Processes, Industrial Chemical Library, vol. 4, Elsevier Press, New York.

(8) Austin, George T. 1984. Shreve's Chemical Process Industries, fifth edition, McGraw Hill, New York.

Shipments of Corn Refining Products (MRaw Input Quantity | Transformed Input Quantity

| Source | (1) | (2) | (3) | (3) | (1) | (2) | ERS 1992 (3) | ERS 1993 (3) |
|---|---|---|---|---|---|---|---|---|
| Units | Million lbs | Million lbs | Thousand sh tons dry | Thousand sh tons dry wt. | Million lbs | Million lbs | Million lbs | Million lbs |
| Year | 1993 | 1992 | 1992 | 1993 | 1993 | 1992 | | |
| CORN STARCH | 5,556 | 6,340 | | | 5,556 | 6,340 | | |
| SYRUPS | 26,955 | | | | 26,955 | | | |
| HFCS 42 | 8,140 | | 2,812 | 2,951 | 8,140 | | 7,921 | 8,313 |
| HFCS 55 | 10,441 | | 3,871 | 4,198 | 10,441 | | 10,055 | 10,904 |
| HFCS TOTAL | 18,580 | | 6,683 | 7,149 | 18,580 | | 17,976 | 19,217 |
| TOTAL DOMES | 32,511 | | | | 32,511 | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| TOTAL EXPOR | 739 | | 739 | | | Average |
| CORN OIL | 799 | | 799 | | | |
| G. FEED, C. OI | 11,388 | | 11,388 | | Notes: | The Corn Refiners only |
| GLUTEN MEAL | 2,031 | | 2,031 | | | their members. ERS es |
| STEEPWATER | 458 | | 458 | | | this percentage is the e |
| TOTAL SHIPME | 47,926 | | 47,926 | | | |
| CORN STARCH | | 6340 | | 6340 | | |
| WHEAT STARCH | | 276 | | 276 | | |
| POTATO STARCH | | 207 | | 207 | | |
| TAPIOCA STARCH | | 69 | | 69 | | |
| TOTAL STARCH | | 6,892 | | 6892 | | |

Notes: Information is presented here from three sources for comparison. Based on the ERS and Corn Refiners data it appears that Corn Refiners members produce nearly all of the starch and corn syrup products. On this basis the corn refiners commercial shipments numbers are converted to dry weight to complete a mass balance, presented below.

Shipments of Corn Refining Products (Million lbs)

| | Raw Input Quantity | Units | Source | Notes | Transformed Input Quantity | Units | Notes |
|---|---|---|---|---|---|---|---|
| CORN STARCH | 5,556 | Million lbs | (1) | I added the category "other glucose" | 5,556 | Million lbs dry wt. | Commercial wt. equals dry wt. |
| REFINERY PR | 26,955 | Million lbs | (1) | to account for the difference between | | | |
| OTHER GLUCO | 8,375 | Million lbs | (1) | refinery products, which includes | 7,286 | Million lbs dry wt. | Estimate at 85% solids. |
| HFCS 42 | 8,140 | Million lbs | (1) | all of the syrups, and the totals for | 5,779 | Million lbs dry wt. | 71% solids (3). |
| HFCS 55 | 10,441 | Million lbs | (1) | HFCS. | 8,039 | Million lbs dry wt. | 77% solids (3). |
| HFCS TOTAL | 18,580 | Million lbs | (1) | | | | |
| TOTAL DOMES | 32,511 | Million lbs | (1) | | | | |
| TOTAL EXPOR | 739 | Million lbs | (1) | | | | |
| CORN OIL | 799 | Million lbs | (1) | | 799 | Million lbs dry wt. | Estimated as commercial |
| G. FEED, C. OI | 11,388 | Million lbs | (1) | | 11,388 | Million lbs dry wt. | weight equals dry weight |
| GLUTEN MEAL | 2,031 | Million lbs | (1) | | 2,031 | Million lbs dry wt. | for these products. |
| STEEPWATER | 458 | Million lbs | (1) | | 229 | Million lbs dry wt. | 50% solids (7). |
| TOTAL SHIPME | 47,926 | Million lbs | (1) | | 41,107 | Million lbs dry wt. | |
| WATER | - | Million lbs | (1) | | | | |

Notes: The wt. fraction of corn ending up in each product type is calculated based on the total consumption of corn by the wet corn milling industry, excluding corn grind for ethanol. Since this is based on dry weight, the difference between the total dry wt. and the wt. of corn used, gives the fraction of water in the corn, as received. Th 12.32% , is reasonable, so it is assumed that our calculations are relatively representative of the industry.

Total Wet Corn Mill Consumption of Corn

| Year | Raw Input Quantity | Units | Source | Tranformed Quantity | Units |
|---|---|---|---|---|---|
| 1987 | 723 | Million Bushels | (3) | 40,488 | Million lbs |
| 1988 | 757 | Million Bushels | (3) | 42,392 | Million lbs |
| 1989 | 766 | Million Bushels | (3) | 42,896 | Million lbs |

| | | | | |
|---|---|---|---|---|
| 1990 | 791 Million Bushels | (3) | 44,296 | Million lbs |
| 1991 | 811 Million Bushels | (3) | 45,416 | Million lbs |
| 1992 | 839 Million Bushels | (3) | 46,984 | Million lbs |
| 1993 | 865 Million Bushels | (3) | 48,440 | Million lbs |
| 1994 | 905 Million Bushels | (3) | 50,680 | Million lbs |

Conversion of Glucose Quantity into Relative Starch Quantity (to account for gain in mass from conversion process).

| Chemical Gain | Raw Input Quantity | Source | Notes |
|---|---|---|---|
| | 4.10% | (8) | p. 572 |
| | 5.80% | (3) | p. 70 |
| | 11.11% | (7) | p. 219, Based on Stiochiometry |
| We Use | 4.95% | | Average of two estimated values |

Average

| Total Sugars | Starch Equivalent | Units |
|---|---|---|
| 21,105 | 20,109 | Million lbs dry wt. |

Comparison of Estimates of Theoretical Yield with Calculated Value from ERS and CRA Data.

| Theoretical Yiel | Based on CRA Annual Prod. (lb) | ERS (3) (lb/bu) | % | CGA (6) (lb/bu) | % | | NREL | |
|---|---|---|---|---|---|---|---|---|
| Corn In | 46,883 | | 56 | | 56.00 | | 579,078,355 | |
| Starch | 25,665 | 54.74% | 31.5 | 56.25% | 32.00 | 57.14% | 345,601,903 | 59.68% |
| Oil (crude) | 799 | 1.70% | 1.55 | 2.77% | 1.60 | 2.86% | 23,338,321 | 4.03% |
| Gluten Feed | 11,388 | 24.29% | 13.5 | 24.11% | 11.40 | 20.36% | 73,552,278 | 12.70% |
| Gluten Meal | 2,031 | 4.33% | 2.65 | 4.73% | 3.00 | 5.36% | 25,092,049 | 4.33% |
| Steepwater | 229 | 0.49% - | - | | | | | 80.75% |
| Water | 6,771 | 14.44% | 6.8 | 12.14% | 8.00 | 14.29% | | |
| Total | 40,112 | 85.56% | 49.2 | 87.86% | 48.00 | 85.71% | | |

Notes: The calculated yields are thus reasonable. Oil yield is lower than both the ERS and CGA theoretical values. This may be because some corn germ is sold to non-CRA refiners.

Material Balance Based on ERS and CRA Data

| Annual Prod Referenced to 1 Bushel | Quantity | Units |
|---|---|---|
| Corn in | 56 | lb |
| Starch | 30.66 | lb |
| Oil | 0.95 | lb |
| Gluten Feed | 13.60 | lb |
| Gluten Meal | 2.43 | lb |

If all starch were converted to Glucose, the yield would be:

| | Quantity | Units |
|---|---|---|
| Corn in | 56 | lb |
| Glucose | 32.17 | lb |
| Oil | 0.95 | lb |
| Gluten Feed | 13.60 | lb |
| Gluten Meal | 2.43 | lb |

---

Table 11 Sulfur Dioxide Use in Wet Corn Milling Industry

(1) U.S. EPA, AP-42, Section 9.9.7

(2) NREL Wet Corn Milling Model

| Input | | Quantity | Units | Source | Transformed Quantity |
|---|---|---|---|---|---|
| Sulfur Dioxide | low | 0.06 | lb/bu | (1) | 0.06 |
| | high | 0.11 | | (1) | 0.11 |
| | average | 0.00206 | kg/kg corn | (2) | 0.12 |
| Sulfur Use | | | | | 0.058 |

Notes: Sulfur dioxide use is converted to sulfur use using the ratio of weights of sulfur and sulfur dioxide.

---

Table 12 Ash Production from Coal Consumption

(1) Utility Data Institute. 1995. EEI Power Statistics Database.

(2) Babcock and Wilcox. 1992. Steam: Its Generation and Use, 40th Edition, S.C. Stulz and J.B. Kitto (eds.).

(3) Energy Information Administration. 1994. Manufacturing Consumption of Energy: 1991, DOE/EIA 0512(91).

(4) United States Department of Energy, Energy Information Administration. 1993. Annual Energy Review: 1993, DOE/EIA-0384(93).

There are two sources of ash in FBC systems, the naturally occuring ash in the coal, and ash formed from sulfur combining with the calcium in the bed. This reaction involves the conversion of calcium carbonate into calcium oxide ($CaCO_3 \rightarrow CaO$) and the subsequent formation of $CaSO_4$ from $SO_2$. Thus two moles of $SO_2$ are removed for every mole of Ca. In addition, $CO_2$ is emitted in the process.

| | | Source |
|---|---|---|
| Reactions | $CaCO_3 \rightarrow CaO(s) + CO_2(g)$ | (2) |
| | $SO_2(g) + 1/2\, O_2(g) + CaO(s) \rightarrow CaSO_4(s)$ | (2) |

Ash Production from Coal Ash and Sulfur Removal

| | Value | Units | Source | Notes |
|---|---|---|---|---|
| Coal Sulfur Con | 2.50 | Percent | Estimate | Reference (1) data indicates that the utility average sulfur content in Iowa, Indiana and Illinois in 1993 was about 1.5%. |
| Coal Ash Conte | 7.70 | Percent | (1) | |
| Coal Energy Co | 22.276 | Million Btu/ton | (3) | |
| Energy Consum | 52,255 | Btu/bu | Table 3 | |
| Energy Consum | 0.0023 | tons coal/bu | Calculated | |
| Energy Consum | 4.69 | lb coal/bu | Calculated | |
| Ash From Coal | 0.36 | lb/bu | Calculated | |
| Ash From Sulfu | 118.33 | lb/ton coal | Calculated | |
| Ash From Sulfu | 0.28 | lb/bu | Calculated | |
| | | | | |
| Total Ash | 0.64 | lb/bu | Calculated | |

Carbon Dioxide Production from Limestone Consumption

| | Quantity | Units | Notes: |
|---|---|---|---|
| Sulfur Removal | 27.87 | lb sulfur removed per ton c | Calculated as the total sulfur in Coal minus that emitted from emissions table above. |
| Carbon Dioxide | 38.25 | lb CO2 emitted per ton coa | Based on Stoichiometry |
| Carbon Dioxide | 0.09 | lb/bu | |

EOF

| | | Table 5 | Table 12 | Table 7 | Table 6 | |
|---|---|---|---|---|---|---|
| | | Energy Cons. | From CaCO3 | WM Particula | Toxic Release | Total |
| ality poor. | NOx | 4.78E-02 | - | - | - | 4.78E-02 |
| ality poor. | SOx | 5.19E-02 | - | - | - | 5.19E-02 |
| ality poor. | PM-10 | 3.15E-02 | - | - | - | 3.15E-02 |
| | Total Particula | - | - | 5.42E-02 | - | 5.42E-02 |
| ality poor. | CO | 4.38E-02 | - | - | - | 4.38E-02 |
| ality poor. | CO2 | 1.55E+01 | 8.97E-02 | - | - | 1.56E+01 |
| ality poor. | Non-Methane | 1.73E-04 | - | - | - | 1.73E-04 |
| ality poor. | Methane | 1.52E-04 | - | - | - | 1.52E-04 |
| ality poor. | N2O | 1.34E-02 | - | - | - | 1.34E-02 |
| | HCL | - | - | - | 3.57E-04 | 3.57E-04 |
| | Ammonia | - | - | - | 8.85E-05 | 8.85E-05 |
| | Chlorine | - | - | - | 3.91E-05 | 3.91E-05 |
| | Sulfuric Acid | - | - | - | 2.41E-05 | 2.41E-05 |

| | Table 5 | Table 12 | Table 7 | Table 6 | |
|---|---|---|---|---|---|
| | Energy Con | From CaCO | WM Particu | Toxic Relea | Total |
| NOx | 100.00% | - | - | - | 100.00% |
| SOx | 100.00% | - | - | - | 100.00% |
| PM-10 | 100.00% | - | - | - | 100.00% |
| Total Partic | - | - | 100.00% | - | 100.00% |
| CO | 100.00% | - | - | - | 100.00% |
| CO2 | 99.43% | 0.57% | - | - | 100.00% |
| Non-Methan | 100.00% | - | - | - | 100.00% |
| Methane | 100.00% | - | - | - | 100.00% |
| N2O | 100.00% | - | - | - | 100.00% |
| HCL | - | - | - | 100.00% | 100.00% |
| Ammonia | - | - | - | 100.00% | 100.00% |
| Chlorine | - | - | - | 100.00% | 100.00% |
| Sulfuric Aci | - | - | - | 100.00% | 100.00% |

ry aggregate data.
ry aggregate data.
ry aggregate data.

conforms to other published estimates.

conforms to other published estimates.

conforms to other published estimates.

conforms to other published estimates.

conforms to other published estimates.

Toxic Releases for SIC 2046
All releases in lb

This table contains raw data on the release of toxic materials by the wet corn milling industry. The data was downloaded from the TRI database, as accessed through the RTK (Right To Know) network in June of 1995. Because of difficulty in downloading a suitably formatted electronic data set, the information was instead compiled from a hard copy printout. The data were input to this spreadsheet and extensively checked, however there is always the possiblity of error.

The raw data include information on a fairly large number of pollutants. Seven of the facilities listed here provided information on the route from which each toxic release was generated. Responses by each facility were consistent, and indicate that most of the toxic material released is associated with processes such as corn starch modification, ion exchange resin regeneration, and ethanol production. Since these processes are not necessary to the production of glucose, these emissions are not assigned to glucose manufacture. The toxics that are associated with glucose manufacture are ammonia, HCL, chlorine, and sulfuric acid. The list below gives a brief description of how each of the toxic chemicals associated with wet corn milling are used.

| | |
|---|---|
| Hydrochloric Acid | Used for ion exchange regeneration, pH adjustment, and in some cases for conversion of starch to glucose. |
| Ammonia | Used as a nutrient (nitrogen source) in either wastewater treatment or for fermentation. |
| Sulfuric Acid | Used as a pH adjuster and for ion exchange regeneration. |
| Chlorine | Used to treat well water or cooling water. Some chlorine emissions may be associated with coal combustion emissions to the stack. |
| Ammonium Sulfate | Probably also associated with use of ammonia as nutrient. |
| Ethylene Oxide | Used to modify starches |
| Ethylene Glycol | From the reaction of ethylene oxide with water. |
| Propylene Oxide | Used to modify starches |
| Propylene Glycol | From the reaction of propylene oxide with water. |
| Phosphoric Acid | Used for ion exchange regeneration and as nutrient in wastewater. |
| Methanol | Byproduct of ethanol production? |
| Acetaldehyde | ? |
| Sodium Sulfate | ? |
| Sodium Hydroxide | Used for pH control. |
| Freon 113 | Refrigerant. |
| Nitric Acid | ? |
| Peracetic Acid | Used to modify starches and in production of HFCS. |
| Cyclohexane | Dehydrating agent in the production of ethanol. |
| Lead Compounds | Emissions from coal combustion. |
| Nickel Compounds | Emissions from coal combustion. |
| Selenium | Emissions from coal combustion. |
| Vanadium | Emissions from coal combustion. |
| Barium | Emissions from coal combustion. |
| Manganese | Emissions from coal combustion. |
| Styrene | ? |
| Butadiene | ? |
| Ammonium Nitrate | Probably also associated with use of ammonia as nutrient. |

| | | |
|---|---|---|
| Methanol | Byproduct of ethanol production? | This set of pollutants is associated with the large ADM facilities which produce ethanol. I am assuming that they are thus associated with processes other than the basic glucose manufacture. |
| Epichlorohydrin | Used to modify starches. | |
| Dibromoterafluoroehtane | Refrigerant. | |
| Bromotrifluoromethane | Refrigerant. | |
| Trichlorofluoromethane | Refrigerant. | |
| Dichlorodifluoromethane | Refrigerant. | |
| Hydrogen Fluoride | ? | |
| Toluene | ? | |
| Benzene | ? | |
| N-Butyl Alcohol | ? | |
| Vinyl Acetate | ? | |
| Xylene | ? | |

Total Toxic Releases of Ammonia, HCL, Chlorine, and Sulfuric Acid
All releases in lb

| Year | Grind (million bu) | Ammonia Fug Air | Stack Air | Water | Land | HCL Fug Air | Stack Air | Water | Land | Chlorine Fug Air | Stack Air | Water | Land | Sulfuric Acid Fug Air | Stack Air | Water | Land |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1987 | 1104 | 416721 | 1000 | 50250 | 50459 | 16578 | 20996 | 0 | 4750 | 1,500 | 0 | 250 | 0 | 1,002 | 538 | 13 | 0 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1988 | 1160 | 68669 | 3686 | 161420 | 250 | 11331 | 7870 | 0 | 750 | 3,670 | 10,252 | 250 | 0 | 1,751 | 1,013 | 0 | 0 |
| 1989 | 1221 | 81151 | 5052 | 710368 | 1450 | 16055 | 32073 | 11 | 1011 | 7,172 | 12,000 | 250 | 0 | 1,504 | 791 | 0 | 0 |
| 1990 | 1221 | 19706 | 8332 | 776472 | 6865 | 14241 | 34203 | 5 | 1000 | 2,755 | 10 | 1,277 | 0 | 1,032 | 59 | 755 | 0 |
| 1991 | 1318 | 18264 | 5384 | 427024 | 13576 | 12987 | 1261725 | 600 | 27000 | 2,501 | 159,896 | 11,176 | 0 | 268 | 61 | 0 | 0 |
| 1992 | 1375 | 16252 | 4437 | 266877 | 0 | 7214 | 955691 | 250 | 200 | 1,267 | 155,055 | 1,433 | 0 | 272 | 104,443 | 0 | 0 |
| 1993 | 1413 | 71687 | 1725 | 56649 | 0 | 12010 | 977391 | 0 | 15910 | 2,487 | 4,887 | 1 | 1 | 532 | 120,459 | 5 | 1,182 |
| | | 692450 | 29616 | 2449060 | 72600 | 90416 | 3289949 | 866 | 50621 | 21,352 | 342,100 | 14,637 | 1 | 6,361 | 227,364 | 773 | 1,182 |
| | | 692450 | 29616 | 2449060 | 72600 | 90416 | 3289949 | 866 | 50621 | 21,352 | 342,100 | 14,637 | 1 | 6,361 | 227,364 | 773 | 1,182 |

Toxic Releases per Bushel Corn Grind
Emissions Intensity (lb/bu)
Based on total corn grind for starch products, byproducts, and ethanol production.

| Year | Grind (million bu) | Ammonia Fug Air | Stack Air | Water | Land | HCL Fug Air | Stack Air | Water | Land | Chlorine Fug Air | Stack Air | Water | Land | Sulfuric Acid Fug Air | Stack Air | Water | Land |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1987 | 1104 | 0.000377465 | 9.1E-07 | 4.6E-05 | 4.6E-05 | 1.5E-05 | 1.9E-05 | 0 | 4.3E-06 | 1.36E-06 | 0.00E+00 | 2.26E-07 | 0.00E+00 | 9.08E-07 | 4.87E-07 | 1.18E-08 | 0.00E+00 |
| 1988 | 1160 | 5.91974E-05 | 3.2E-06 | 0.00014 | 2.2E-07 | 9.8E-06 | 6.8E-06 | 0 | 6.47E-07 | 3.16E-06 | 8.84E-06 | 2.16E-07 | 0.00E+00 | 1.51E-06 | 8.73E-07 | 0.00E+00 | 0.00E+00 |
| 1989 | 1221 | 6.64627E-05 | 4.1E-06 | 0.00058 | 1.2E-06 | 1.3E-05 | 2.6E-05 | 9E-09 | 8.28E-07 | 5.87E-06 | 9.83E-06 | 2.05E-07 | 0.00E+00 | 1.23E-06 | 6.48E-07 | 0.00E+00 | 0.00E+00 |
| 1990 | 1221 | 1.61392E-05 | 6.8E-06 | 0.00064 | 5.6E-06 | 1.2E-05 | 2.8E-05 | 4.1E-09 | 8.19E-07 | 2.26E-06 | 8.19E-09 | 1.05E-06 | 0.00E+00 | 8.45E-07 | 4.83E-08 | 6.18E-07 | 0.00E+00 |
| 1991 | 1318 | 1.38574E-05 | 4.1E-06 | 0.00032 | 1E-05 | 9.9E-06 | 0.00096 | 4.6E-07 | 2.05E-05 | 1.90E-06 | 1.21E-04 | 8.48E-06 | 0.00E+00 | 2.03E-07 | 4.63E-08 | 0.00E+00 | 0.00E+00 |
| 1992 | 1375 | 1.18196E-05 | 3.2E-06 | 0.00019 | 0 | 5.2E-06 | 0.0007 | 1.8E-07 | 1.5E-07 | 9.21E-07 | 1.13E-04 | 1.04E-06 | 0.00E+00 | 1.98E-07 | 7.60E-05 | 0.00E+00 | 0.00E+00 |
| 1993 | 1413 | 5.07339E-05 | 1.2E-06 | 4E-05 | 0 | 8.5E-06 | 0.00069 | 0 | 1.1E-05 | 1.76E-06 | 3.46E-06 | 7.08E-10 | 7.08E-10 | 3.77E-07 | 8.53E-05 | 3.54E-09 | 8.37E-07 |
| Average | | 8.50964E-05 | 3.4E-06 | 0.00028 | 9E-06 | 1E-05 | 0.00035 | 9.3E-08 | 5.5E-06 | 2.46E-06 | 3.66E-05 | 1.6E-06 | 1.01E-10 | 7.53E-07 | 2.33E-05 | 9.05E-08 | 1.2E-07 |

Plant Level Data
Toxic Releases in SIC 2046 - Wet Corn Milling
Emissions in lbs

Fugitive Air

| Plant | City | Year | Hydrochlor | Ammonia | Ammonium | Chlorine | Sulfuric Ac | Ethylene O | Ethylene G | Propylene | Propylene | Phosphoric | Methanol | Acetaldehy | Epichloroh | Sodium Su | Sodium Hy | Dibromoter | Bromotriflu |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| American Maize Products | Decatur | 1987 | 250 | 0 | | 0 | | | | | | | | | | | 0 | | |
| | | 1988 | 250 | 0 | | 0 | | | | | | | | | | | 0 | | |
| | | 1989 | 250 | 0 | | 0 | | | | | | | | | | | | | |
| | | 1990 | 250 | 0 | | 0 | | | | | | | | | | | | | |
| | | 1991 | 250 | 0 | | 0 | | | | | | | | | | | | | |
| | | 1992 | 250 | 0 | | 0 | | | | | | | | | | | | | |
| | | 1993 | 250 | 0 | | 0 | | | | | | | | | | | | | |
| A. E. Staley Mfg. Co. | Van Buren | 1987 | | 250 | | | | | | | | | 77000 | | | | | | |
| | | 1988 | | 250 | | | | | | | | | 276,916 | | | | 0 | | |
| | | 1989 | | 250 | | | | | | | | | 120,912 | | | | | | |
| | | 1990 | | 250 | | | 0 | | | 250 | | 0 | 110,000 | | | | | | |
| | | 1991 | | 200 | | | | | | | | 0 | 42,000 | | | | | | |
| | | 1992 | | 200 | | | | | | | | 0 | 25,000 | | | | | | |
| | | 1993 | | 5 | | | 5 | | | 250 | | 0 | 22,900 | | | | | | |
| CPC International Inc. | Stockton | 1987 | 750 | 5000 | 0 | | | | | | | | | | | 0 | 250 | | |
| | | 1988 | 750 | 1900 | 0 | 250 | 250 | | | | | | | | | | 250 | | |
| | | 1989 | 750 | 2100 | 0 | 250 | 250 | | | | | | | 0 | | | | | |
| | | 1990 | 750 | 0 | | | 5 | | | | | | | 1000 | | | | | |
| | | 1991 | 750 | | | | 5 | | | | | | | 1000 | | | | | |
| | | 1992 | 750 | | | | 5 | | | | | 0 | | 1000 | | | | | |
| | | 1993 | 750 | | | | 5 | | | | | | | 1000 | | | | | |
| A.E. Staley Mfg. Co. | Monte Vista | 1987 | | 0 | | | | | | | | | | | | | 0 | | |
| | | 1988 | 250 | | | | | | | | | | | | | | 0 | | |
| | | 1989 | 250 | | | | | | | | | | | | | | | | |
| | | 1990 | 250 | 0 | | | | | | | | | | | | | | | |
| | | 1991 | 5 | | | | | | | | | | | | | | | | |
| | | 1992 | 5 | | | | | | | | | | | | | | | | |
| | | 1993 | 5 | | | | | | | | | | | | | | | | |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ADM Corn Processing | Clinton | 1987 | 750 | 250 | | 250 | 250 | 250 | | | | | | | | 250 | | |
| | | 1988 | 750 | 250 | | 250 | 250 | 250 | | | | | | | | 250 | | |
| | | 1989 | 750 | 250 | 250 | 250 | 250 | 250 | | | | | | 250 | | | | |
| | | 1990 | 750 | 250 | 250 | 250 | 250 | 250 | | | | | | 250 | | | | |
| | | 1991 | 250 | 250 | 0 | 0 | 0 | 5 | | | | | | 5 | | | 0 | 610 |
| | | 1992 | 250 | | 0 | 0 | 0 | 5 | | | | 0 | | 5 | | | 7500 | |
| | | 1993 | 250 | 250 | 0 | 0 | 250 | 5 | | | | | | 5 | | | | |
| Hubinger Co. | Keokuk | 1987 | 250 | 750 | | | | | | 0 | | | | 0 | | 0 | | |
| | | 1988 | 250 | 750 | | 750 | | | | 0 | | | | 0 | | 0 | | |
| | | 1989 | 250 | 750 | | 250 | | | | 0 | | | | 0 | | | | |
| | | 1990 | 250 | 750 | | 259 | 250 | | | 0 | | | | 0 | | | | |
| | | 1991 | 52 | 12 | | 0 | 0 | | | 0 | | | | 0 | | | | |
| | | 1992 | 250 | 250 | | 0 | 0 | | | 0 | | | | 0 | | | | |
| | | 1993 | 250 | | | | 0 | | | 0 | | | | 0 | | | | |
| ADM Corn Processing | Cedar Rapids | 1987 | | | | | | | | | | | | | | | | |
| | | 1988 | 250 | 250 | | 250 | 250 | | | | | | | | | 250 | | |
| | | 1989 | 250 | 250 | | 250 | 250 | | | | | | | | | | | |
| | | 1990 | 250 | 250 | | 250 | 250 | | | | | | | | | | | |
| | | 1991 | 250 | 250 | | 250 | 250 | | | | | | | | | | | |
| | | 1992 | 250 | 250 | | 250 | 250 | 60 | 0 | | | | | | | | | |
| | | 1993 | 1204 | 250 | | 250 | 250 | 84 | 0 | | | | | | | | | |
| Cargill Inc. | Cedar Rapids | 1987 | 2152 | | | | | | | | | | | | 0 | 0 | | |
| | | 1988 | 820 | | | | 0 | 26 | 0 | | | | | | | 0 | | |
| | | 1989 | 818 | | | | | 39 | 0 | | | | | | | | | |
| | | 1990 | 750 | 0 | | | | 250 | 0 | | | | | | | | | |
| | | 1991 | 809 | | | | | 25 | 0 | | | | | | | | | |
| | | 1992 | 1204 | | | | | | | | | | | | | | | |
| | | 1993 | 1204 | | | | | 84 | | | | | | | | | | |
| Penford Products Co. | Cedar Rapids | 1987 | 6000 | | | 250 | | 750 | 0 | | | | | | | 750 | | |
| | | 1988 | 750 | | | 250 | | 16600 | 0 | 250 | | | | | | 0 | | |
| | | 1989 | 750 | | | 250 | | 750 | 0 | | | | | | | | | |
| | | 1990 | 750 | 0 | | 250 | | 750 | 0 | | | | | | | | | |
| | | 1991 | 5 | | | 5 | | 250 | 0 | | | | | | | | | |
| | | 1992 | 250 | | | 5 | | 250 | 0 | | | | | | | | | |
| | | 1993 | 250 | | | 5 | | 250 | 0 | 250 | | | | | | | | |
| Cargill Inc. | Eddyville | 1987 | 987 | | 0 | 0 | 0 | | | | | | | | 0 | 0 | | |
| | | 1988 | 1300 | 20000 | 0 | 170 | 0 | | | | | | | | | 0 | | |
| | | 1989 | 1400 | 43000 | 0 | 170 | | | | | | | | | | | | |
| | | 1990 | 1547 | 14006 | | 1229 | 0 | | | | | | | | | | | |
| | | 1991 | 1432 | 6778 | | 1229 | 0 | | | | | | | | | | | |
| | | 1992 | | 4536 | | | 0 | | | | 0 | | | | | | | |
| | | 1993 | 1430 | 5138 | | 1221 | 0 | | | | 0 | | | | | | | |
| A. E. Staley Mfg. Co.(Eldarado | Decatur | 1987 | 250 | 2600 | | 250 | 0 | 250 | 0 | 8000 | | | | | 250 | 0 | | |
| | | 1988 | 250 | 1550 | | 750 | 250 | 250 | 250 | 8000 | | | 20000 | | | 250 | | |
| | | 1989 | 250 | 1550 | | 5000 | 250 | 250 | 250 | 7000 | | | 18445 | | | | | |
| | | 1990 | 250 | 750 | | 250 | 5 | 250 | 5 | 750 | | | | | | | | |
| | | 1991 | 250 | 250 | | 5 | 5 | 250 | 5 | 250 | | | | | | | | |
| | | 1992 | 250 | 250 | | 5 | 5 | 5 | 5 | 250 | | | | | | | | |
| | | 1993 | 250 | 250 | | 10 | 5 | 5 | 5 | 250 | | | | | | | | |
| National Starch & Chemical Co | Indianapolis | 1987 | 205 | | | 0 | 1 | | | 27 | | | | | 0 | 62 | | |
| | | 1988 | 55 | | | 0 | | | | 30 | | | | | | 12 | | |
| | | 1989 | 156 | | | 2 | 3 | | | 29 | | | | | | | | |
| | | 1990 | 145 | 0 | | 2 | 6 | | | 20828 | | | | | | | | |
| | | 1991 | 134 | | | 2 | 3 | | | 30 | | | | | | | | |
| | | 1992 | 133 | | | 2 | 2 | | | 17 | | | | | | | | |
| | | 1993 | 100 | | | 1 | 2 | | | 31 | | | | | | | | |
| A. E. Staley Mfg. Co. (Sagamo | Lafayette | 1987 | 250 | 250 | | 250 | 0 | | | 250 | 0 | | | | 0 | | | |
| | | 1988 | 250 | | | 250 | 0 | | | 250 | 0 | | | | | | | |
| | | 1989 | 250 | 250 | | 250 | 0 | | | | 0 | | | | | | | |
| | | 1990 | 250 | 250 | | 5 | 0 | | | 250 | 0 | | | | | | | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1991 | 250 | 250 | | 5 | | | | | | | |
| | | 1992 | 250 | 250 | | 250 | | | 250 | | | | |
| | | 1993 | 250 | 250 | | 250 | | | 250 | | | | |
| Minnesota Corn Processors | Marshall | 1987 | | | | | | | | | | | |
| | | 1988 | 0 | 0 | | 0 | 0 | | | | | | |
| | | 1989 | 0 | 0 | | 0 | 0 | | | | | | |
| | | 1990 | 0 | 0 | | 0 | 0 | | | | | | |
| | | 1991 | 250 | | | 0 | 0 | | | | | | |
| | | 1992 | 0 | | | 0 | 0 | | | | | | |
| | | 1993 | 0 | | | 0 | 0 | | | | | | |
| National Starch & Chemical Co | Kansas City | 1987 | 22 | 5 | | | 1 | | 4 | 0 | | 0 | 10 |
| | | 1988 | 6 | 2 | | | 1 | | 4 | 1 | | | 11 |
| | | 1989 | 12 | 1 | | | 1 | | 1 | 0 | | | |
| | | 1990 | 2 | 1 | | | 1 | | 5 | 0 | | | |
| | | 1991 | 2 | 0 | | | 0 | | 8 | 0 | | | |
| | | 1992 | 2 | 1 | | | 0 | | 6 | 0 | | | |
| | | 1993 | 2 | 1 | | | 0 | | 314 | 0 | | | |
| Minnesota Corn Processors | Columbus | 1987 | | | | | | | | | | | |
| | | 1988 | | | | | | | | | | | |
| | | 1989 | | | | | | | | | | | |
| | | 1990 | | 0 | | | | | | | | | |
| | | 1991 | | | | | | | | | | | |
| | | 1992 | | | | 0 | 0 | | | 0 | | | |
| | | 1993 | 0 | | | 0 | 0 | | | | | | |
| ADM Corn Processing | Montezuma | 1987 | 0 | 0 | | 0 | 0 | | | | | | 0 |
| | | 1988 | 0 | | | | 0 | | | | | | |
| | | 1989 | | | | | 0 | | | | | | |
| | | 1990 | | 0 | | | 5 | | | | | | |
| | | 1991 | | | | | | | | | | | |
| | | 1992 | | | | | | | | | | | |
| | | 1993 | | | | | | | | | | | |
| Cargill Inc. | Dayton | 1987 | 1702 | 5423 | | | 0 | | | | | 0 | 0 |
| | | 1988 | 1700 | | | | 0 | | | | | | 0 |
| | | 1989 | 3600 | 0 | | | 0 | | | | | | |
| | | 1990 | 3600 | 0 | | | 0 | | | | | | |
| | | 1991 | 3600 | 0 | | | 0 | | | | | | |
| | | 1992 | 1260 | 0 | | | 0 | | | | | | |
| | | 1993 | 1260 | 0 | | | 0 | | | | | | |
| A. E. Staley Mfg. Co. | Loudon | 1987 | 250 | 250 | | 250 | 250 | | | | | 0 | 0 |
| | | 1988 | 250 | 4967 | | 250 | 250 | | | | | | 0 |
| | | 1989 | | | | | | | | | | | |
| | | 1990 | 250 | 250 | | | 250 | | | | | | |
| | | 1991 | 5 | 19 | | | 0 | | | | | | |
| | | 1992 | 5 | 15 | | | 0 | | | | | | |
| | | 1993 | 5 | 43 | | | 5 | | | | | | |
| Cargill Inc. | Memphis | 1987 | 1710 | 401693 | 0 | | 0 | | | | | 0 | 0 |
| | | 1988 | 2200 | 38000 | 0 | | 0 | | | | | | 0 |
| | | 1989 | 5069 | 32000 | 0 | | 0 | | | | | | |
| | | 1990 | 2942 | 0 | | | 0 | | | | | | |
| | | 1991 | 2943 | 0 | | | 0 | | | | | | |
| | | 1992 | 1100 | 0 | | | 0 | | | | | | |
| | | 1993 | 1100 | 0 | | | 0 | | | | | | |
| ADM Corn Processing | Decatur | 1987 | 250 | 250 | | 250 | 250 | | | | | | 250 |
| | | 1988 | 250 | 250 | | 250 | 250 | | | | | | 250 |
| | | 1989 | 250 | 250 | | 250 | 250 | | | | 0 | | |
| | | 1990 | 250 | 2449 | | 5 | 5 | | | | 0 | | |
| | | 1991 | 750 | 10000 | | 750 | 5 | | | | 0 | | |
| | | 1992 | | 10000 | | 750 | 5 | | | | | | |
| | | 1993 | 750 | 65000 | | 750 | 5 | | | | | | |
| American Maize Products | Hammond | 1987 | 0 | 0 | | 0 | | 250 | 250 | | | 0 | 0 |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1988 | 0 | 250 | | 0 | | 250 | | 250 | | | | | | | | | |
| | | 1989 | 0 | 250 | | 0 | | 250 | | 250 | | | | | | | | | |
| | | 1990 | 5 | 250 | | 5 | | 250 | | 250 | | | | | | | | | |
| | | 1991 | | 5 | | 5 | | 250 | | 5 | | | | | | | | | |
| | | 1992 | 5 | 250 | | 5 | | | | 1362 | | | | | | | | | |
| | | 1993 | 1700 | 250 | | | | | | 1800 | | | | | | | | | |
| American Maize Products | Dimmitt | 1987 | | | | | | | | | | | | | | | | | |
| | | 1988 | 250 | 250 | | 250 | | | | | | | | | | | 250 | | |
| | | 1989 | 250 | 250 | | 250 | | | | | | | | | | | | | |
| | | 1990 | 250 | 250 | | 250 | | | | | | | | | | | | | |
| | | 1991 | 250 | 250 | | 250 | | | | | | | | | | | | | |
| | | 1992 | 250 | 250 | | | | | | | | | | | | | | | |
| | | 1993 | 250 | 250 | | | | | | | | | | | | | | | |
| CPC | Winston-Salem | 1987 | 800 | | | | 250 | | | | | | | | | 0 | 250 | | |
| | | 1988 | 750 | | | | 250 | | | | | | | | | | 250 | | |
| | | 1989 | 750 | | | | 250 | | | | | | | | | | | | |
| | | 1990 | 750 | 0 | | | 5 | | | | | | | | | | | | |
| | | 1991 | 750 | | | | | | | | | | | | | | | | |
| | | 1992 | 750 | | | | 5 | | | | | | | | | | | | |
| | | 1993 | 750 | | | | 5 | | | | | | | | | | | | |
| Total | | 1987 | 16,578 | 416,721 | 0 | 1,500 | 1,002 | 1,500 | 0 | 8,531 | 0 | 0 | 77,000 | 0 | 0 | 250 | 1,822 | 0 | 0 |
| | | 1988 | 11,331 | 68,669 | 0 | 3,670 | 1,751 | 17,376 | 250 | 8,784 | 0 | 1 | 276,916 | 20,000 | 0 | 0 | 1,773 | 0 | 0 |
| | | 1989 | 16,055 | 81,151 | 250 | 7,172 | 1,504 | 1,539 | 250 | 7,280 | 0 | 0 | 120,912 | 18,445 | 250 | 0 | 0 | 0 | 0 |
| | | 1990 | 14,241 | 19,706 | 250 | 2,755 | 1,032 | 1,750 | 5 | 22,333 | 0 | 0 | 110,000 | 1,000 | 250 | 0 | 0 | 0 | 0 |
| | | 1991 | 12,987 | 18,264 | 0 | 2,501 | 268 | 780 | 5 | 293 | 0 | 0 | 42,000 | 1,000 | 5 | 0 | 0 | 0 | 610 |
| | | 1992 | 7,214 | 16,252 | 0 | 1,267 | 272 | 320 | 5 | 1,885 | 0 | 0 | 25,000 | 1,000 | 5 | 0 | 0 | 7,500 | 0 |
| | | 1993 | 12,010 | 71,687 | 0 | 2,487 | 532 | 428 | 5 | 3,145 | 0 | 0 | 22,900 | 1,000 | 5 | 0 | 0 | 0 | 0 |
| Average | | | 12,917 | 98,921 | 71 | 3,050 | 909 | 3,385 | 74 | 7,464 | 0 | 0 | 96,390 | 6,064 | 74 | 36 | 514 | 1,071 | 87 |

Toxic Releases in SIC 2046 - Wet Corn Milling
Emissions in lbs

Stack Air

| Plant | City | Year | Hydrochlor | Ammonia | Ammonium | Chlorine | Sulfuric Ac | Ethylene O | Ethylene G | Propylene | Propylene | Phosphoric | Methanol | Sodium Su | Sodium Hy | Hydrogen F | Acetaldehy | Epichloroh | Dibromotet |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| American Maize Products | Decatur | 1987 | 750 | | | | | | | | | | | | 0 | | | | |
| | | 1988 | 0 | | | | | | | | | | | | 0 | | | | |
| | | 1989 | 0 | | | | | | | | | | | | | | | | |
| | | 1990 | 5 | | | | | | | | | | | | | | | | |
| | | 1991 | 250 | | | | | | | | | | | | | | | | |
| | | 1992 | 250 | | | | | | | | | | | | | | | | |
| | | 1993 | 250 | | | | | | | | | | | | | | | | |
| A. E. Staley Mfg. Co. | Van Buren | 1987 | | 250 | | | | | | | | | 215000 | | 0 | | | | |
| | | 1988 | | 250 | | | | | | | | | 200,000 | | | | | | |
| | | 1989 | | 250 | | | | | | | | | 179,599 | | | | | | |
| | | 1990 | | 250 | | | 0 | | | 250 | | 0 | 200,178 | | | | | | |
| | | 1991 | | 0 | | | | | | | | 0 | 78,000 | | | | | | |
| | | 1992 | | 0 | | | | | | | | 0 | 30,000 | | | | | | |
| | | 1993 | | 0 | | | 5 | | | 19 | | 0 | 4,500 | | | | | | |
| CPC International Inc. | Stockton | 1987 | 250 | 0 | 0 | | | | | | | | | 0 | 250 | | | | |
| | | 1988 | 250 | 0 | 0 | 10,000 | 250 | | | | | | | | 250 | | | 250 | |
| | | 1989 | 250 | 0 | 0 | 12000 | | | | | | | | | | | 0 | | |
| | | 1990 | 27 | | | | 5 | | | | | | | | | | 550 | | |
| | | 1991 | 250 | | | | 5 | | | | | | | | | | 750 | | |
| | | 1992 | 250 | | | | 5 | | | | | | | | | | 750 | | |
| | | 1993 | 250 | | | | 5 | | | | | | | | | | 750 | | |
| A. E. Staley Mfg. Co. | Monte Vista | 1987 | | | | | | | | | | | | | 0 | | | | |
| | | 1988 | 250 | | | | | | | | | | | | 0 | | | | |
| | | 1989 | 250 | | | | | | | | | | | | | | | | |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1990 | 250 | | | | | | | | | | | | | | | | |
| | | 1991 | 250 | | | | | | | | | | | | | | | | |
| | | 1992 | 5 | | | | | | | | | | | | | | | | |
| | | 1993 | 5 | | | | | | | | | | | | | | | | |
| ADM Corn Processing | Clinton | 1987 | 250 | | 0 | 0 | 0 | 0 | | | | | | | 0 | | | | |
| | | 1988 | 250 | 0 | | 0 | 0 | 0 | | | | | | | 0 | | | | |
| | | 1989 | 250 | 0 | 250 | 0 | 0 | 0 | | | | | | | | | | | |
| | | 1990 | 250 | 0 | 250 | 0 | 0 | 0 | | | | | | | | | | 250 | |
| | | 1991 | 1200000 | 780 | 0 | 0 | 0 | 250 | | | | | | | | 0 | | 0 | 6300 |
| | | 1992 | 740000 | | 0 | | 0 | 250 | | | | | 5 | | | 72000 | | 0 | 0 |
| | | 1993 | 740000 | | 0 | 0 | 0 | 250 | | | | | | | | 62000 | | 5 | |
| Hubinger Co. | Keokuk | 1987 | 0 | 0 | | | | | | 0 | | | | | 0 | | | 0 | |
| | | 1988 | 0 | 0 | | 0 | | | | 0 | | | | | 0 | | | 0 | |
| | | 1989 | 0 | 0 | | 0 | | | | | 0 | | | | | | | 0 | |
| | | 1990 | 0 | 0 | | 0 | 0 | | | 0 | | | | | | | | 0 | |
| | | 1991 | 0 | 0 | | 24883 | 0 | | | 0 | | | | | | 0 | | 0 | |
| | | 1992 | 5 | 5 | | 21910 | 0 | | | | 0 | | | | | | | 0 | |
| | | 1993 | 5 | | | | 0 | | | 0 | | | | | | | | 0 | |
| ADM Corn Processing | Cedar Rapids | 1987 | | | | | | | | | | | | | | | | | |
| | | 1988 | 0 | 0 | | 0 | 0 | | | | | | | | 0 | | | | |
| | | 1989 | 0 | 0 | | 0 | 0 | | | | | | | | | | | | |
| | | 1990 | 0 | 0 | | 0 | 0 | | | | | | | | | | | | |
| | | 1991 | 0 | 0 | | 129,940 | 0 | | | | | | | | | 0 | | | |
| | | 1992 | 0 | 0 | | 132,640 | 0 | 0 | 0 | | | | | | | | | | |
| | | 1993 | 250 | 0 | | 250 | 0 | 250 | | | | | | | | | | | |
| Cargill Inc. | Cedar Rapids | 1987 | 662 | 0 | | | | | | | | | | 0 | 0 | | | | |
| | | 1988 | 900 | | | | 0 | 0 | 0 | | | | | | 0 | | | | |
| | | 1989 | 818 | | | | | 0 | 0 | | | | | | | | | | |
| | | 1990 | 750 | | | | | 0 | 0 | | | | | | | | | | |
| | | 1991 | 2726 | | | | | 0 | 0 | | | | | | | 0 | | | |
| | | 1992 | 30127 | | | | | | | | | | | | | | | | |
| | | 1993 | 28342 | | | | | 0 | 0 | | | | | | | | | | |
| Penford Products Co. | Cedar Rapids | 1987 | 250 | | | 0 | | 250 | 0 | | | | | | 0 | | | | |
| | | 1988 | 250 | | | 0 | | 250 | 0 | 250 | | | | | 0 | | | | |
| | | 1989 | 250 | | | 0 | | 750 | 0 | | | | | | | | | | |
| | | 1990 | 250 | | | 0 | | 750 | 0 | | | | | | | | | | |
| | | 1991 | 5 | | | 0 | | 750 | 0 | | | | | | | 0 | | | |
| | | 1992 | 250 | | | 250 | | 250 | 0 | | | | | | | | | | |
| | | 1993 | 250 | 250 | | | | 250 | 0 | | | | | | | | | | |
| Cargill Inc. | Eddyville | 1987 | 83 | | 0 | 0 | | | | | | | | 0 | 0 | | | | |
| | | 1988 | 80 | 0 | 0 | 0 | 0 | | | | | | | | 0 | | | | |
| | | 1989 | 300 | 0 | 0 | 0 | | | | | | | | | | | | | |
| | | 1990 | 145 | | 0 | 0 | 0 | | | | | | | | | | | | |
| | | 1991 | 8999 | 0 | | 4323 | 0 | | | | | | | | | 0 | | | |
| | | 1992 | | 0 | | | 11180 | | | | | 0 | | | | | | | |
| | | 1993 | 9258 | 0 | | 4635 | 11000 | | | | | 0 | | | | | | | |
| A. E. Staley Co.(eldorado) | Decatur | 1987 | 11200 | 250 | | 0 | 0 | 2909 | 0 | 50000 | | | | 0 | 0 | | 35000 | | |
| | | 1988 | 750 | 750 | | 250 | 250 | 3227 | 250 | 5600 | | | | | 250 | | | | |
| | | 1989 | 1200 | 750 | | 0 | 250 | 3760 | 250 | 3500 | | | | | | | 35000 | | |
| | | 1990 | 1182 | 1780 | | 5 | 5 | 1513 | 5 | 250 | | | | | | | | | |
| | | 1991 | 750 | 630 | | 250 | 5 | 1920 | 5 | 3960 | | | | | | 0 | | | |
| | | 1992 | 750 | 750 | | 250 | 5 | 217 | 5 | 2160 | | | | | | | | | |
| | | 1993 | 619 | 720 | | 1 | 5 | 2 | 5 | 2100 | | | | | | | | | |
| National Starch & Chemical Co | Indianapolis | 1987 | 1209 | | | 0 | 25 | | | 19335 | | | | 0 | 88 | | | | |
| | | 1988 | 1349 | | | 2 | | | | 20733 | | | | | 46 | | | | |
| | | 1989 | 1052 | | | 0 | 26 | | | 19898 | | | | | | | | | |
| | | 1990 | 1426 | | | 0 | 20 | | | 20828 | | | | | | | | | |
| | | 1991 | 1036 | | | 0 | 27 | | | 20219 | | | | | | 0 | | | |
| | | 1992 | 466 | | | 0 | 18 | | | 13337 | | | | | | | | | |
| | | 1993 | 417 | | | 1 | 29 | | | 107711 | | | | | | | | | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A. E. Staley Mfg. Co. (Sagamo | Lafayette | 1987 | 0 | 0 | | 0 | | 71576 | 0 | | 129 | | |
| | | 1988 | 11 | | | 0 | 0 | 51259 | 0 | | | | |
| | | 1989 | 11 | 250 | | 0 | 0 | | 0 | | | | |
| | | 1990 | 250 | 0 | | 0 | 0 | 33961 | 0 | | | | |
| | | 1991 | 250 | | | | | 31819 | | | | | 0 |
| | | 1992 | 250 | | | | | 24985 | | | | | |
| | | 1993 | 250 | | | | | 29250 | | | | | |
| Minnesota Corn Processors | Marshall | 1987 | | | | | | | | | | | |
| | | 1988 | 0 | 0 | | 0 | 0 | | | | | | |
| | | 1989 | 0 | 0 | | 0 | 0 | | | | | | |
| | | 1990 | 0 | 0 | | 0 | 0 | | | | | | |
| | | 1991 | 0 | | | 0 | 0 | | | | | | 0 |
| | | 1992 | 250 | | | 0 | 0 | | | | | | |
| | | 1993 | 250 | | | 0 | 0 | | | | | | |
| National Starch & Chemical Co | Kansas City | 1987 | 404 | 0 | | | 13 | 5594 | 0 | | 0 | 9 | |
| | | 1988 | 200 | 1936 | | | 13 | 14574 | 1 | | | 7 | |
| | | 1989 | 442 | 2312 | | | 15 | 5376 | 3 | | | | |
| | | 1990 | 596 | 5797 | | | 14 | 7219 | 3 | | | | |
| | | 1991 | 868 | 3219 | | | 14 | 8037 | 3 | | | | 0 |
| | | 1992 | 1027 | 2927 | | | 15 | 9254 | 3 | | | | |
| | | 1993 | 2 | 0 | | | 0 | 0 | 3 | | | | |
| Minnesota Corn Processors | Columbus | 1987 | | | | | | | | | | | |
| | | 1988 | | | | | | | | | | | |
| | | 1989 | | | | | | | | | | | |
| | | 1990 | | | | | | | | | | | |
| | | 1991 | | | | | | | | | | | 0 |
| | | 1992 | | | | 0 | 5 | | 5 | | | | |
| | | 1993 | 250 | | | 0 | 5 | | | | | | |
| ADM Corn Processing | Montezuma | 1987 | 0 | 0 | | 0 | 0 | | | | | 0 | |
| | | 1988 | 0 | | | | 0 | | | | | | |
| | | 1989 | | | | | 0 | | | | | | |
| | | 1990 | | | | | 0 | | | | | | |
| | | 1991 | | | | | | | | | | | 0 |
| | | 1992 | | | | | | | | | | | |
| | | 1993 | | | | | | | | | | | |
| Cargill Inc. | Dayton | 1987 | 232 | 0 | | | 0 | | | | 0 | 0 | |
| | | 1988 | 330 | | | | 0 | | | | | 0 | |
| | | 1989 | 200 | 0 | | | 0 | | | | | | |
| | | 1990 | 70 | 0 | | | 0 | | | | | | |
| | | 1991 | 7000 | 0 | | | 0 | | | | | | 0 |
| | | 1992 | 76580 | 0 | | | 83000 | | | | | | |
| | | 1993 | 89350 | 0 | | | 98200 | | | | | | |
| A. E. Staley Mfg. Co. | Loudon | 1987 | 750 | 0 | | 0 | 0 | | | | 0 | 0 | |
| | | 1988 | 750 | 0 | | 0 | 0 | | | | | 0 | |
| | | 1989 | | | | | | | | | | | |
| | | 1990 | 250 | 5 | | | 5 | | | | | | |
| | | 1991 | 51 | 5 | | | 5 | | | | | | 0 |
| | | 1992 | 40 | 5 | | | 5 | | | | | | |
| | | 1993 | 43 | 5 | | | 5 | | | | | | |
| Cargill Inc. | Memphis | 1987 | 456 | 0 | 0 | | 0 | | | | 0 | 0 | |
| | | 1988 | 1000 | 0 | 0 | | 0 | | | | | 0 | |
| | | 1989 | 1300 | 740 | 0 | | 0 | | | | | | |
| | | 1990 | 1247 | 0 | | | 0 | | | | | | |
| | | 1991 | 5848 | 0 | | | 0 | | | | | | 0 |
| | | 1992 | 69200 | 0 | | | 10200 | | | | | | |
| | | 1993 | 75600 | 0 | | | 11200 | | | | | | |
| ADM Corn Processing | Decatur | 1987 | 250 | 250 | | 0 | 250 | | | | | 250 | |
| | | 1988 | 250 | 250 | | 0 | 250 | | | | | 250 | |
| | | 1989 | 250 | 250 | | 0 | 250 | | | 250 | | | |
| | | 1990 | 250 | | 250 | 0 | 5 | | | 250 | | | |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1991 | 250 | 250 | | 0 | 5 | | | | | | 250 | | | 0 | | | 0 |
| | | 1992 | | 250 | | 0 | 5 | | | | | | | | | | | | 0 |
| | | 1993 | 250 | 250 | | | | | | | | | | | | | | | |
| American Maize Products | Hammond | 1987 | 250 | 250 | | 0 | | 44852 | | 58667 | | | | 250 | 0 | | | | |
| | | 1988 | 250 | 250 | | 0 | | 750 | | 1133 | | | | | | | | | |
| | | 1989 | 250 | 250 | | 0 | | 65600 | | 96400 | | | | | | | | | |
| | | 1990 | 5 | 250 | | 5 | | 65991 | | 19377 | | | | | | | | | |
| | | 1991 | 3942 | 250 | | 250 | | 5857 | | 690 | | | | | | 0 | | | |
| | | 1992 | 3991 | 250 | | 5 | | | | 34886 | | | | | | | | | |
| | | 1993 | 1500 | 250 | | | | | | 42000 | | | | | | | | | |
| American Maize Products | Dimmitt | 1987 | | | | | | | | | | | | | 250 | | | | |
| | | 1988 | 250 | 250 | | | | | | | | | | | | | | | |
| | | 1989 | 250 | 250 | | | | | | | | | | | | | | | |
| | | 1990 | 250 | 250 | | | | | | | | | | | | | | | |
| | | 1991 | 250 | 250 | | 250 | | | | | | | | | | 0 | | | |
| | | 1992 | 250 | 250 | | | | | | | | | | | | | | | |
| | | 1993 | 250 | 250 | | | | | | | | | | | | | | | |
| CPC | Winston-Salem | 1987 | 4000 | | | | 250 | | | | | | | | 250 | | | | |
| | | 1988 | 750 | | | | 250 | | | | | | | | 250 | | | | |
| | | 1989 | 25000 | | | | 250 | | | | | | | | | | | | |
| | | 1990 | 27000 | | | | 5 | | | | | | | | | | | | |
| | | 1991 | 29000 | | | | | | | | | | | | | 0 | | | |
| | | 1992 | 32000 | | | | 5 | | | | | | | | | | | | |
| | | 1993 | 30000 | | | | 5 | | | | | | | | | | | | |
| Total | | 1987 | 20,996 | 1,000 | 0 | 0 | 538 | 48,011 | 0 | 205,172 | 0 | 0 | 215,000 | 379 | 1,097 | 0 | 35,000 | 0 | 0 |
| | | 1988 | 7,870 | 3,686 | 0 | 10,252 | 1,013 | 4,227 | 250 | 93,549 | 0 | 1 | 200,000 | 0 | 1,053 | 0 | 0 | 250 | 0 |
| | | 1989 | 32,073 | 5,052 | 250 | 12,000 | 791 | 70,110 | 250 | 125,174 | 0 | 3 | 179,849 | 0 | 0 | 0 | 35,000 | 0 | 0 |
| | | 1990 | 34,203 | 8,332 | 500 | 10 | 59 | 68,254 | 5 | 81,885 | 0 | 3 | 200,428 | 0 | 0 | 0 | 550 | 250 | 0 |
| | | 1991 | ######## | 5,384 | 0 | 159,896 | 61 | 8,777 | 5 | 64,725 | 0 | 3 | 78,250 | 0 | 0 | 0 | 750 | 0 | 6,300 |
| | | 1992 | 955,691 | 4,437 | 0 | 155,055 | 104,443 | 717 | 5 | 84,622 | 0 | 8 | 30,005 | 0 | 0 | 72,000 | 750 | 0 | 0 |
| | | 1993 | 977,391 | 1,725 | 0 | 4,887 | 120,459 | 752 | 5 | 181,080 | 0 | 3 | 4,500 | 0 | 0 | 62,000 | 750 | 5 | 0 |
| Average | | | 469,993 | 4,231 | 107 | 48,871 | 32,481 | 28,693 | 74 | 119,458 | 0 | 3 | 129,719 | 54 | 307 | 19,143 | 10,400 | 72 | 900 |

Toxic Releases in SIC 2046 - Wet Corn Milling
Emissions in lbs

Water

| Plant | City | Year | | Hydrochlor | Ammonia | Ammonium | Chlorine | Sulfuric Ac | Ethylene O | Ethylene G | Propylene | Propylene | Phosphoric | Methanol | Sodium Su | Sodium Hy | Hydrogen F | Acetaldehy | Epichloroh | Dibromotet |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| American Maize Products | Decatur | | 1987 | 0 | | | | | | | | | | | | 0 | | | | |
| | | | 1988 | 0 | | | | | | | | | | | | 0 | | | | |
| | | | 1989 | 0 | | | | | | | | | | | | | | | | |
| | | | 1990 | 0 | | | | | | | | | | | | | | | | |
| | | | 1991 | 0 | | | | | | | | | | | | | | | | |
| | | | 1992 | 0 | | | | | | | | | | | | | | | | |
| | | | 1993 | 0 | | | | | | | | | | | | | | | | |
| A. E. Staley Mfg. Co. | Van Buren | | 1987 | 0 | 0 | 0 | | | | | | | | 0 | 0 | 0 | | | | |
| | | | 1988 | 0 | 0 | 0 | 0 | 0 | | | | | | 0 | | 0 | | | | |
| | | | 1989 | 0 | 0 | 0 | 0 | | | | | | | 0 | | | | 0 | | |
| | | | 1990 | | 0 | | | 0 | | | 0 | | 0 | 0 | | | | | | |
| | | | 1991 | | 0 | | | | | | | | 0 | 250 | | | | | | |
| | | | 1992 | | 22 | | | | | | | | 0 | 5 | | | | | | |
| | | | 1993 | 0 | 82 | | | 5 | | | 5 | | 250 | 5 | | | | | | |
| CPC International Inc. | Stockton | | 1987 | 0 | 0 | 0 | | | | | | | | | 0 | 0 | | | | |
| | | | 1988 | 0 | 0 | 0 | 0 | 0 | | | | | | | | 0 | | 0 | | |
| | | | 1989 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | |
| | | | 1990 | | | | | | | | | | | | | | | | | |
| | | | 1991 | | | | | | | | | | | | | | | | | |
| | | | 1992 | | | | | | | | | | | | | | | | | |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1993 | 0 | | | | | | | | | | | | | | | | |
| A.E. Staley | Monte Vista | 1987 | | | | | | | | | | | | | | | | | |
| | | 1988 | | | | | | | | | | | | | | | | | |
| | | 1989 | | | | | | | | | | | | | | | | | |
| | | 1990 | | | | | | | | | | | | | | | | | |
| | | 1991 | | | | | | | | | | | | | | | | | |
| | | 1992 | | | | | | | | | | | | | | | | | |
| | | 1993 | | | | | | | | | | | | | | | | | |
| ADM Corn Processing | Clinton | 1987 | 0 | 50,000 | | 250 | 0 | 0 | | | | | | | 0 | | | | |
| | | 1988 | 0 | 90000 | | 250 | 0 | 0 | | | | | | | 0 | | | | |
| | | 1989 | 0 | 90000 | 0 | 250 | 0 | 0 | | | | | | | | | | 0 | |
| | | 1990 | 5 | 90000 | 0 | 250 | 5 | 0 | | | | | | | | | | 0 | |
| | | 1991 | 0 | 870 | 0 | 0 | 0 | 0 | | | | | | | | 0 | | 0 | 0 |
| | | 1992 | 0 | | 0 | 0 | 0 | 0 | | | | | 0 | | | 0 | | 0 | 0 |
| | | 1993 | 0 | | 0 | 0 | 0 | 0 | | | | | | | | 0 | | 0 | |
| Hubinger Co. | Keokuk | 1987 | 0 | | | | | | | 0 | | | | | 0 | | | 0 | |
| | | 1988 | 0 | 0 | | 0 | | | | 0 | 0 | | | | 0 | | | 0 | |
| | | 1989 | 0 | 30000 | | 0 | | | | 0 | | | | | | | | 0 | |
| | | 1990 | 0 | 30000 | | 0 | 0 | | | 0 | | | | | | | | 0 | |
| | | 1991 | 0 | 72000 | | 0 | 0 | | | 0 | | | | | | | | 0 | |
| | | 1992 | 0 | 105,485 | | 0 | 0 | | | | 0 | | | | | | | 0 | |
| | | 1993 | 0 | | | | 0 | | | 0 | | | | | | | | 0 | |
| ADM Corn Processing | Cedar Rapids | 1987 | | | | | | | | | | | | | | | | | |
| | | 1988 | 0 | 0 | | 0 | 0 | | | | | | | 0 | | | | | |
| | | 1989 | 0 | 0 | | 0 | 0 | | | | | | | | | | | | |
| | | 1990 | 0 | 0 | | 0 | 0 | | | | | | | | | | | | |
| | | 1991 | 0 | 0 | | 0 | 0 | | | | | | | | | | | | |
| | | 1992 | 250 | 250 | | 0 | | 0 | 0 | | | | | | | | | | |
| | | 1993 | 0 | 0 | | 0 | | 0 | | | | | | | | | | | |
| Cargill Inc. | Cedar Rapids | 1987 | 0 | | | | 0 | | | | | | | 0 | 0 | | | | |
| | | 1988 | 0 | | | | 0 | 0 | 0 | | | | | | 0 | | | | |
| | | 1989 | 0 | | | | | 0 | 0 | | | | | | | | | | |
| | | 1990 | 0 | | | | | 0 | 0 | | | | | | | | | | |
| | | 1991 | 600 | | | | | 0 | 0 | | | | | | | | | | |
| | | 1992 | | | | | | | | | | | | | | | | | |
| | | 1993 | 0 | | | | | 0 | 0 | | | | | | | | | | |
| Penford Products Co. | Cedar Rapids | 1987 | 0 | | | 0 | | 0 | 0 | | | | | | 0 | | | | |
| | | 1988 | 0 | | | 0 | | 34800 | 0 | 0 | | | | | 0 | | | | |
| | | 1989 | 0 | | | 0 | | 0 | 0 | | | | | | | | | | |
| | | 1990 | 0 | | | 0 | | 0 | 0 | | | | | | | | | | |
| | | 1991 | 0 | | | 0 | | 0 | 0 | | | | | | | | | | |
| | | 1992 | 0 | | | 250 | 0 | 0 | 0 | | | | | | | | | | |
| | | 1993 | 0 | | | 0 | | 0 | 0 | | | | | | | | | | |
| Cargill Inc. | Eddyville | 1987 | 0 | | 456225 | 0 | | | | | | | | 2907968 | 0 | | | | |
| | | 1988 | 0 | 7900 | 440000 | 0 | 0 | | | | | | | | 0 | | | | |
| | | 1989 | 0 | 515000 | 70000 | 0 | | | | | | | | | | | | | |
| | | 1990 | 0 | 547916 | | 0 | 0 | | | | | | | | | | | | |
| | | 1991 | 0 | 237695 | | 0 | 0 | | | | | | | | | | | | |
| | | 1992 | | 73164 | | | 0 | | | | | 0 | | | | | | | |
| | | 1993 | 0 | 43366 | | 0 | 0 | | | | | 0 | | | | | | | |
| A. E. Staley Mfg. Co.(eldorado | Decatur | 1987 | 0 | 0 | | 0 | 0 | 2909 | 0 | 0 | | | | 0 | 0 | | 0 | | |
| | | 1988 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | | | | | 0 | | | | |
| | | 1989 | 0 | 0 | | 0 | 0 | 0 | 250 | 0 | | | | | | | 0 | | |
| | | 1990 | 0 | 0 | | 0 | 750 | 0 | 0 | 0 | | | | | | | | | |
| | | 1991 | 0 | 0 | | 0 | 0 | 0 | 0 | | 0 | | | | | | | | |
| | | 1992 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | | | | | | | | | |
| | | 1993 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | | | | | | | | | |
| National Starch & Chemical Co | Indianapolis | 1987 | 0 | | | 0 | 0 | | | 0 | | | | 0 | 0 | | | | |
| | | 1988 | 0 | | | 0 | | | | 0 | | | | | 0 | | | | |
| | | 1989 | 0 | | | 0 | 0 | | | 0 | | | | | | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1990 | 0 | | | 0 | 0 | 0 | | | |
| | | 1991 | 0 | | | 0 | 0 | 0 | | | |
| | | 1992 | 0 | | | 0 | 0 | 0 | | | |
| | | 1993 | 0 | | | 1 | 0 | 0 | | | |
| A. E. Staley Mfg. Co. (Sagamo | Lafayette | 1987 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | |
| | | 1988 | 0 | | | 0 | 0 | 0 | 0 | | |
| | | 1989 | 11 | 0 | | 0 | 0 | | 0 | | |
| | | 1990 | 0 | 0 | | 0 | 0 | 0 | 0 | | |
| | | 1991 | | | | | | | | | |
| | | 1992 | | | | | | | | | |
| | | 1993 | 0 | | | | | | | | |
| Minnesota Corn Processors | Marshall | 1987 | | | | | | | | | |
| | | 1988 | 0 | 0 | | 0 | 0 | | | | |
| | | 1989 | 0 | 0 | | 0 | 0 | | | | |
| | | 1990 | 0 | 0 | | 0 | 0 | | | | |
| | | 1991 | 0 | | | 0 | 0 | | | | |
| | | 1992 | 0 | | | 0 | 0 | | | | |
| | | 1993 | 0 | | | 0 | 0 | | | | |
| National Starch & Chemical Co | Kansas City | 1987 | 0 | 0 | | | 13 | 0 | 0 | 0 | 0 |
| | | 1988 | 0 | 0 | | | 0 | 0 | 0 | | 0 |
| | | 1989 | 0 | 0 | | | 0 | 0 | 0 | | |
| | | 1990 | 0 | 0 | | | 0 | 0 | 0 | | |
| | | 1991 | 0 | 0 | | | 0 | 0 | 0 | | |
| | | 1992 | 0 | 0 | | | 0 | 0 | 0 | | |
| | | 1993 | 0 | 0 | | | 0 | 0 | 0 | | |
| Minnesota Corn Processors | Columbus | 1987 | | | | | | | | | |
| | | 1988 | | | | | | | | | |
| | | 1989 | | | | | | | | | |
| | | 1990 | | | | | | | | | |
| | | 1991 | | | | | | | | | |
| | | 1992 | | | | 0 | 0 | | 0 | | |
| | | 1993 | 0 | | | 0 | 0 | | | | |
| ADM Corn Processing | Montezuma | 1987 | 0 | 0 | | 0 | 0 | | | | 0 |
| | | 1988 | 0 | | | | 0 | | | | |
| | | 1989 | | | | | 0 | | | | |
| | | 1990 | | | | | 0 | | | | |
| | | 1991 | | | | | | | | | |
| | | 1992 | | | | | | | | | |
| | | 1993 | 0 | | | | | | | | |
| Cargill Inc. | Dayton | 1987 | 0 | 0 | | | 0 | | | 0 | 0 |
| | | 1988 | 0 | | | | 0 | | | | 0 |
| | | 1989 | 0 | 0 | | | 0 | | | | |
| | | 1990 | 0 | 0 | | | 0 | | | | |
| | | 1991 | 0 | 0 | | | 0 | | | | |
| | | 1992 | 0 | 0 | | | 0 | | | | |
| | | 1993 | 0 | 0 | | | 0 | | | | |
| A.E. Staley Mfg. Co. | Loudon | 1987 | 0 | 0 | | 0 | 0 | | | 0 | 0 |
| | | 1988 | 0 | 0 | | 0 | 0 | | | | 0 |
| | | 1989 | | | | | | | | | |
| | | 1990 | 0 | 0 | | | 0 | | | | |
| | | 1991 | 0 | 0 | | | 0 | | | | |
| | | 1992 | 0 | 0 | | | 0 | | | | |
| | | 1993 | 0 | 13201 | | | 0 | | | | |
| Cargill Inc. | Memphis | 1987 | 0 | 0 | 0 | | 0 | | | 0 | 0 |
| | | 1988 | 0 | 0 | 0 | | 0 | | | | 0 |
| | | 1989 | 0 | 0 | 0 | | 0 | | | | |
| | | 1990 | 0 | 0 | | | 0 | | | | |
| | | 1991 | 0 | 0 | | | 0 | | | | |
| | | 1992 | 0 | 0 | | | 0 | | | | |
| | | 1993 | 0 | 0 | | | 0 | | | | 0 |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ADM Corn Processing | Decatur | 1987 | 0 | 0 | | 0 | 0 | | | | | | | | 0 | | | | |
| | | 1988 | 0 | 250 | | 0 | 0 | | | | | | | | 0 | | | | |
| | | 1989 | 0 | 0 | | 0 | 0 | | | | | | 0 | | | | | | |
| | | 1990 | 0 | 0 | | 0 | 0 | | | | | | 0 | | | | | | |
| | | 1991 | 0 | 0 | | 0 | 0 | | | | | | 0 | | | | | | 0 |
| | | 1992 | | 0 | | 0 | 0 | | | | | | | | | | | | 0 |
| | | 1993 | 0 | | | | | | | | | | | | | | | | |
| American Maize Products | Hammond | 1987 | 0 | 250 | | 0 | | 250 | | 250 | | | | 1221456 | 3328388 | | | | |
| | | 1988 | 0 | 63270 | | 0 | | 0 | | 0 | | | | | | | | | |
| | | 1989 | 0 | 75368 | | 0 | | 0 | | 0 | | | | | | | | | |
| | | 1990 | 0 | 108556 | | 1027 | | 0 | | 0 | | | | | | | | | |
| | | 1991 | 0 | 116459 | | 11176 | | 0 | | 0 | | | | | | | | | |
| | | 1992 | 0 | 87956 | | 1183 | | | | 0 | | | | | | | | | |
| | | 1993 | 0 | 0 | | | | | | 0 | | | | | | | | | |
| American Maize | Dimmitt | 1987 | | | | | | | | | | | | | | | | | |
| | | 1988 | | | | | | | | | | | | | | | | | |
| | | 1989 | | | | | | | | | | | | | | | | | |
| | | 1990 | | | | | | | | | | | | | | | | | |
| | | 1991 | | | | | | | | | | | | | | | | | |
| | | 1992 | | | | | | | | | | | | | | | | | |
| CPC | Winston-Salem | 1993 | 0 | | | | | | | | | | | | | | | | |
| | | 1987 | | | | | | | | | | | | | | | | | |
| | | 1988 | | | | | | | | | | | | | | | | | |
| | | 1989 | | | | | | | | | | | | | | | | | |
| | | 1990 | | | | | | | | | | | | | | | | | |
| | | 1991 | | | | | | | | | | | | | | | | | |
| | | 1992 | | | | | | | | | | | | | | | | | |
| | | 1993 | 0 | | | | | | | | | | | | | | | | |
| Total | | 1987 | 0 | 50,250 | 456,225 | 250 | 13 | 3,159 | 0 | 250 | 0 | 0 | 0 | ######## | ######## | 0 | 0 | 0 | 0 |
| | | 1988 | 0 | 161,420 | 440,000 | 250 | 0 | 34,800 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | 1989 | 11 | 710,368 | 70,000 | 250 | 0 | 0 | 250 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | 1990 | 5 | 776,472 | 0 | 1,277 | 755 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | 1991 | 600 | 427,024 | 0 | 11,176 | 0 | 0 | 0 | 0 | 0 | 0 | 250 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | 1992 | 250 | 266,877 | 0 | 1,433 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | 1993 | 0 | 56,649 | 0 | 1 | 5 | 0 | 0 | 5 | 0 | 250 | 5 | 0 | 0 | 0 | 0 | 0 | 0 |

Toxic Releases in SIC 2046 - Wet Corn Milling
Emissions in lbs

Land

| Plant | City | Year | Hydrochlor | Ammonia | Ammonium | Chlorine | Sulfuric Ac | Ethylene O | Ethylene G | Propylene | Sodium Hy | Styrene |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| American Maize Products | Decatur | 1987 | 0 | | | | | | | | 0 | |
| | | 1988 | 0 | | | | | | | | 0 | |
| | | 1989 | 0 | | | | | | | | | |
| | | 1990 | 0 | | | | | | | | | |
| | | 1991 | 0 | | | | | | | | | |
| | | 1992 | 0 | | | | | | | | | |
| | | 1993 | 0 | | | | | | | | | |
| A. E. Staley Mfg. Co. | Van Buren | 1987 | 0 | 0 | 0 | | | | | | 0 | |
| | | 1988 | 0 | 0 | 0 | 0 | 0 | | | | 0 | |
| | | 1989 | 0 | 0 | 0 | 0 | | | | | | |
| | | 1990 | | 0 | | | 0 | | | 0 | | |
| | | 1991 | | 0 | | | | | | | | |
| | | 1992 | | 0 | | | | | | | | |
| | | 1993 | | 0 | | | 0 | | | 0 | | |
| CPC Internationl Inc. | Stockton | 1987 | 0 | 0 | 0 | | | | | | 0 | |
| | | 1988 | 0 | 0 | 0 | 0 | 0 | | | | 0 | |
| | | 1989 | 0 | 0 | 0 | 0 | 0 | | | | | |
| | | 1990 | | | | | | | | | | |
| | | 1991 | | | | | | | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1992 | | | | | | | | | | |
| | | 1993 | | | | | | | | | | |
| A.E. Staley | Monte Vista | 1987 | 250 | | | | | | | | | |
| | | 1988 | | | | | | | | | 250 | |
| | | 1989 | 250 | | | | | | | | | |
| | | 1990 | 250 | | | | | | | | | |
| | | 1991 | | | | | | | | | | |
| | | 1992 | | | | | | | | | | |
| | | 1993 | | | | | | | | | | |
| ADM Corn Processing | Clinton | 1987 | 0 | 0 | | 0 | 0 | 0 | | | 0 | |
| | | 1988 | 0 | 0 | | 0 | 0 | 0 | | | 0 | |
| | | 1989 | 0 | 0 | 0 | 0 | 0 | 0 | | | | |
| | | 1990 | 0 | 0 | 0 | 0 | 0 | 0 | | | | |
| | | 1991 | 0 | 0 | 0 | 0 | 0 | 0 | | | | |
| | | 1992 | 0 | | 0 | 0 | 0 | 0 | | | | |
| | | 1993 | 7955 | | 0 | 0 | 0 | 0 | | | | 5 |
| Hubinger Co. | Keokuk | 1987 | 0 | | | | | | | 0 | 0 | |
| | | 1988 | 0 | 0 | | 0 | | | | 0 | 0 | |
| | | 1989 | 0 | 0 | | 0 | | | | 0 | | |
| | | 1990 | 0 | 0 | | 0 | 0 | | | 0 | | |
| | | 1991 | 0 | 0 | | 0 | 0 | | | 0 | | |
| | | 1992 | 0 | 0 | | 0 | 0 | | | 0 | | |
| | | 1993 | 0 | | | | 0 | | | 0 | | |
| ADM Corn Processing | Cedar Rapids | 1987 | | | | | | | | | | |
| | | 1988 | 0 | 0 | | 0 | 0 | | | | 0 | |
| | | 1989 | 0 | 0 | | 0 | 0 | | | | | |
| | | 1990 | 0 | 0 | | 0 | 0 | | | | | |
| | | 1991 | 0 | 0 | | 0 | | | | | | |
| | | 1992 | 0 | 0 | | | | 0 | 0 | | | |
| | | 1993 | | 0 | | 0 | | | | | | |
| Cargill Inc. | Cedar Rapids | 1987 | 0 | | | | | | | | 0 | |
| | | 1988 | 0 | | | | 0 | 0 | 0 | | 0 | |
| | | 1989 | 0 | | | | | 0 | 0 | | | |
| | | 1990 | 0 | | | | 0 | 0 | 0 | | | |
| | | 1991 | 0 | | | | | 0 | 0 | | | |
| | | 1992 | | | | | | | | | | |
| | | 1993 | 0 | | | | | 0 | 0 | | | |
| Penford Products Co. | Cedar Rapids | 1987 | 0 | | | 0 | | 0 | 0 | | 0 | |
| | | 1988 | 750 | | | 0 | | 750 | 0 | 250 | 250 | |
| | | 1989 | 750 | | | 0 | | 0 | 250 | | | |
| | | 1990 | 750 | | | 0 | | 0 | 250 | | | 5 |
| | | 1991 | 27000 | | | 0 | | 0 | 250 | | | 0 |
| | | 1992 | 200 | | | 0 | 0 | 0 | 5 | | | 0 |
| | | 1993 | 7955 | | | 0 | | 0 | 0 | | | 5 |
| Cargill Inc. | Eddyville | 1987 | 0 | 0 | 0 | 0 | | | | | 0 | |
| | | 1988 | 0 | | 3300 | 0 | 0 | | | | 0 | |
| | | 1989 | 0 | 1200 | 0 | 0 | | | | | | |
| | | 1990 | 0 | 6615 | | 0 | 0 | | | | | |
| | | 1991 | 0 | 8576 | | 0 | 0 | | | | | |
| | | 1992 | | 0 | | | 0 | | | | | |
| | | 1993 | 0 | 0 | | 0 | 0 | | | | | |
| A. E. Staley Mfg. Co.(eldorado | Decatur | 1987 | 4500 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | 1988 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | 1989 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | | |
| | | 1990 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | | |
| | | 1991 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | | |
| | | 1992 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | | |
| | | 1993 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | | |
| National Starch & Chemical Co | Indianapolis | 1987 | 0 | | | 0 | 0 | | | 0 | 0 | |
| | | 1988 | 0 | | | 0 | | | | 0 | 0 | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1989 | 0 | | | 0 | 0 | 0 | |
| | | 1990 | 0 | | | 0 | 0 | 0 | |
| | | 1991 | 0 | | | 0 | 0 | 0 | |
| | | 1992 | 0 | | | 0 | 0 | 0 | |
| | | 1993 | 0 | | | 1 | 0 | 0 | |
| A . E. Staley Mfg. Co. (Sagamo | Layfette | 1987 | 0 | 0 | | 0 | 0 | 0 | |
| | | 1988 | 0 | | | 0 | 0 | 0 | |
| | | 1989 | 11 | 0 | | 0 | 0 | | |
| | | 1990 | 0 | | | 0 | | 0 | |
| | | 1991 | | 0 | | | 0 | | |
| | | 1992 | | | | | | | |
| | | 1993 | | | | | | | |
| Minnesota Corn Processors | Marshall | 1987 | | | | | | | |
| | | 1988 | 0 | 0 | | 0 | 0 | | |
| | | 1989 | 0 | 0 | | | 0 | | |
| | | 1990 | 0 | 0 | | 0 | 0 | | |
| | | 1991 | 0 | | | 0 | 0 | | |
| | | 1992 | 0 | | | 0 | 0 | | |
| | | 1993 | 0 | | | | 1182 | | |
| National Starch & Chemical Co | Kansas City | 1987 | 0 | 0 | | | 0 | 0 | 0 |
| | | 1988 | 0 | 0 | | | 0 | 0 | 0 |
| | | 1989 | 0 | 0 | | | 0 | 0 | |
| | | 1990 | 0 | 0 | | | 0 | 0 | |
| | | 1991 | 0 | 0 | | | 0 | 0 | |
| | | 1992 | 0 | 0 | | | 0 | 0 | |
| | | 1993 | 0 | 0 | | | 0 | 0 | |
| Minnesota Corn Processors | Columbus | 1987 | | | | | | | |
| | | 1988 | | | | | | | |
| | | 1989 | | | | | | | |
| | | 1990 | | | | | | | |
| | | 1991 | | | | | | | |
| | | 1992 | | | | 0 | 0 | | |
| | | 1993 | 0 | | | 0 | 0 | | |
| ADM Corn Processing | Montezuma | 1987 | 0 | 0 | | 0 | 0 | | 0 |
| | | 1988 | 0 | | | | 0 | | |
| | | 1989 | | | | | 0 | | |
| | | 1990 | | | | | 0 | | |
| | | 1991 | | | | | | | |
| | | 1992 | | | | | | | |
| | | 1993 | | | | | | | |
| Cargill Inc. | Dayton | 1987 | 0 | 0 | | | 0 | | 0 |
| | | 1988 | 0 | | | | 0 | | 0 |
| | | 1989 | 0 | 0 | | | 0 | | |
| | | 1990 | 0 | 0 | | | 0 | | |
| | | 1991 | 0 | 0 | | | 0 | | |
| | | 1992 | 0 | 0 | | | 0 | | |
| | | 1993 | 0 | 0 | | | 0 | | |
| A. E. Staley Mfg. Co. | Loudon | 1987 | 0 | 0 | | 0 | 0 | | 0 |
| | | 1988 | 0 | 0 | | 0 | 0 | | 0 |
| | | 1989 | | | | | | | |
| | | 1990 | 0 | 0 | | | 0 | | |
| | | 1991 | 0 | 0 | | | 0 | | |
| | | 1992 | 0 | 0 | | | 0 | | |
| | | 1993 | 0 | 0 | | | 0 | | |
| Cargill Inc. | Memphis | 1987 | 0 | 0 | 0 | | 0 | | 0 |
| | | 1988 | 0 | 0 | 0 | | 0 | | 0 |
| | | 1989 | 0 | 0 | 0 | | 0 | | |
| | | 1990 | 0 | 0 | | | 0 | | |
| | | 1991 | 0 | 0 | | | 0 | | |
| | | 1992 | 0 | 0 | | | 0 | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1993 | 0 | 0 | | | 0 | | | | | |
| ADM Corn Processing | Decatur | 1987 | 0 | 250 | | 0 | 0 | | | | 0 | |
| | | 1988 | 0 | 250 | | 0 | 0 | | | | 0 | |
| | | 1989 | 0 | 250 | | 0 | 0 | | | | | |
| | | 1990 | 0 | 250 | | 0 | 0 | | | | | |
| | | 1991 | 0 | 5000 | | 0 | 0 | | | | | |
| | | 1992 | | 0 | | 0 | 0 | | | | | |
| | | 1993 | | | | | | | | | | |
| American Maize Products | Hammond | 1987 | | 50209 | | 0 | | 0 | | 0 | 0 | |
| | | 1988 | 0 | 0 | | 0 | | 0 | | 0 | 0 | |
| | | 1989 | 0 | 0 | | 0 | | 0 | | 0 | | |
| | | 1990 | 0 | 0 | | 0 | | 0 | | 0 | | |
| | | 1991 | 0 | 0 | | 0 | | 0 | | 0 | | |
| | | 1992 | 0 | 0 | | 0 | | | | 0 | | |
| | | 1993 | 0 | 0 | | | | | | 0 | | |
| American Maize Products | Dimmitt | 1987 | | | | | | | | | | |
| | | 1988 | | | | | | | | | | |
| | | 1989 | | | | | | | | | | |
| | | 1990 | | | | | | | | | | |
| | | 1991 | | | | | | | | | | |
| | | 1992 | | | | | | | | | | |
| | | 1993 | | | | | | | | | | |
| CPC | Winston-Salem | 1987 | | | | | | | | | | |
| | | 1988 | | | | | | | | | | |
| | | 1989 | | | | | | | | | | |
| | | 1990 | | | | | | | | | | |
| | | 1991 | | | | | | | | | | |
| | | 1992 | | | | | | | | | | |
| | | 1993 | | | | | | | | | | |
| Total | | 1987 | 4,750 | 50,459 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | 1988 | 750 | 250 | 3,300 | 0 | 0 | 750 | 0 | 250 | 500 | 0 |
| | | 1989 | 1,011 | 1,450 | 0 | 0 | 0 | 0 | 250 | 0 | 0 | 0 |
| | | 1990 | 1,000 | 6,865 | 0 | 0 | 0 | 0 | 250 | 0 | 0 | 5 |
| | | 1991 | 27,000 | 13,576 | 0 | 0 | 0 | 0 | 250 | 0 | 0 | 0 |
| | | 1992 | 200 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 |
| | | 1993 | 15,910 | 0 | 0 | 1 | 1,182 | 0 | 0 | 0 | 0 | 10 |
| Average | | | 7,232 | 10,371 | 471 | 0 | 169 | 107 | 108 | 36 | 71 | 2 |

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hydrogen F | Freon 113 | Peracetic A | Cyclohexan | Xylene | Lead Comp | Nickel Com | Selenium | Vanadium | Barium | Manganese | Nitric Acid | Styrene | Butadiene | Ammonium | N-Butyl Alc | Vinyl Aceta | Benzene | Trichloroflu | Toluene | Dichlorodifluoromethane |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 250 | | | | | | | | | | | | |
| 0 | | | | | | | | | | | | | | | | |
| 0 | | | | | | | | | | | | | | | | |
| 0 | | | | | | | | | | | | | | | | |
| | 22000 | 0 | | | | | | | | | | | | | | |
| | 96800 | 0 | | | | | | | | | | | | | | |
| | 74800 | 0 | | | | | | | | | | | | | | |
| | 74800 | 0 | 0 | 0 | | | | | | | | | | | | |
| | 30800 | 0 | 10 | | 0 | 0 | | | | | | | | | | |
| | 24200 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | |
| | | 0 | 0 | | 0 | | 0 | 0 | 0 | 0 | | | | | | |
| | | | | | | | | | | | 250 | | | | | |
| | | | | | | | | | | | 250 | | | | | |
| | | | | | | | | | | | | 250 | 250 | | | |
| | | | | | | | | | | | | 5 | 5 | | | |
| | | | | | | | | | | | 5 | 5 | 250 | | | |
| | | | | | | | | | | | | 5 | 250 | | | |
| | | | | | | | | | | | 0 | | | 0 | | |
| | | | | | | | | | | | 0 | | | 0 | | |
| | | | | | | | | | | | 0 | | | 0 | | |
| | | | | | | | | | | | 0 | | | | | |
| | | | | | | 0 | | | | | | | | | 250 | 250 |
| | 40000 | | | | | 0 | | | | | | | | | | 3200 |
| | | | | | | 0 | | | | | | | | | | 250 |
| | | | | | | 0 | | | | | | | | | | |
| | | | | | | 0 | | | | | | | | | | |
| | | | | | | 0 | | | | | | | | | | |
| | | | | | | 0 | | | | | | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| 40000 | | | 250 | | |
| 162400 | | | | | |
| 102445 | | | | | |
| 178140 | 0 | 0 | | | |
| | 0 | 0 | | 23800 | 113050 |
| | 0 | 0 | | 24200 | 80600 |
| | | | | 8800 | 46200 |

| |
|---|
| 0 |
| 0 |
| 40613 |
| 110000 |

| Bromotriflu | Freon 113 | Peracetic A | Cyclohexan | Xylene | Lead Comp | Nickel Com | Selenium | Vanadium | Barium | Manganese | Nitric Acid | Styrene | Butadiene | Ammonium | Vinyl Aceta | Benzene | trichloroflur | Toluene | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 62,000 | 0 | 0 | 250 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 250 | 250 | 250 | 0 | 0 | 0 |
| 0 | 299,200 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3,200 | 0 | 0 | 0 | 0 |
| 0 | 177,245 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 250 | 0 | 0 | 0 | 0 |
| 0 | 252,940 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 250 | 250 | 250 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 30,800 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 250 | 5 | 5 | 0 | 0 | 0 | 0 | 23,800 | 0 | 113,050 |
| 0 | 24,200 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 5 | 250 | 0 | 0 | 0 | 0 | 24,200 | 40,613 | 80,600 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 250 | 0 | 0 | 0 | 0 | 8,800 | 110,000 | 46,200 |
| 0 | 120,912 | 0 | 1 | 36 | 0 | 0 | 0 | 0 | 0 | 0 | 72 | 38 | 108 | 0 | 36 | 529 | 36 | 8,114 | 21,516 | 34,264 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 0 | | | | | | | | | | | |
| 120 | | | | | | | | | | | | | | | |
| | 0 | 0 | | | | | | | | | | | | | |
| | 0 | 0 | | | | | | | | | | | | | |
| | 0 | 0 | | | | | | | | | | | | | |
| | 0 | 0 | 250 | 0 | | | | | | | | | | | |
| | 0 | 0 | 0 | | 35280 | 43084 | | | | | | | | | |
| | 0 | 0 | 5 | | 38414 | 51,760 | 960 | 5850 | 22192 | 9137 | | | | | |
| | | 0 | 5 | | 24592 | 36915 | 594 | 5347 | 11467 | 7756 | | | | | |
| | | | | | | | | | | | 0 | | | | |
| | | | | | | | | | | | 0 | | | | |
| | | | | | | | | | | | 0 | | | | |
| | | | | | | | | | | | 0 | 250 | | | |
| | | | | | | | | | | | | 250 | 250 | | |
| | | | | | | | | | | | | 250 | 250 | | |
| | | | | | | | | | | | | 250 | 250 | | |
| | | | | | | | | | | | | 250 | 250 | | |
| | | | | | | | | | | | 0 | | | 0 | |
| | | | | | | | | | | | 0 | | | 0 | |
| | | | | | | | | | | | 0 | | | | |
| | | | | | | | | | | | | | | 0 | |
| | | | | | | | | | | | 0 | | | | |
| | 0 | | | | | 0 | | | | | | | | | 250 |
| | | | | | | 0 | | | | | | | | | 250 |
| | | | | | | 0 | | | | | | | | | 250 |
| | | | | | | 0 | | | | | | | | | |
| | | | | | | 0 | | | | | | | | | |
| | | | | | | 0 | | | | | | | | | |
| | | | | | | 0 | | | | | | | | | |

0
0
0
0 5 0 250

| Bromotriflu | Freon 113 | Peracetic A | Cyclohexan | Xylene | Lead Comp | Nickel Com | Selenium | Vanadium | Barium | Manganese | Nitric Acid | Styrene | Butadiene | Ammonium | Vinyl Aceta | Benzene | Trichloroflu | Toluene |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 5 | | 0 | | | | | | | | | | | 0 | |
| | | | | 5 | | 0 | | | | | | | | | | | 0 | |
| | | | | 5 | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | 250 |
| | | | | | | | | | | | | | | | | | | 0 |
| | | | | | | | | | | | | | | | | | | 750 |
| | | | | | | | | | | | | | | | | | | 750 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 250 | 250 | 0 | 250 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 250 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 250 | 0 | 0 | 0 |
| 0 | 0 | 0 | 250 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 250 | 250 | 0 | 0 | 0 | 0 | 0 |
| 120 | 0 | 0 | 0 | 5 | 35,280 | 43,084 | 0 | 0 | 0 | 0 | 0 | 250 | 250 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 5 | 5 | 38,414 | 51,760 | 960 | 5,850 | 22,192 | 9,137 | 0 | 250 | 250 | 0 | 0 | 0 | 0 | 750 |
| 0 | 0 | 0 | 5 | 5 | 24,592 | 36,915 | 594 | 5,347 | 11,467 | 7,756 | 0 | 500 | 250 | 0 | 0 | 0 | 0 | 750 |
| 17 | 0 | 0 | 37 | 3 | 14,041 | 18,823 | 222 | 1,600 | 4,808 | 2,413 | 0 | 179 | 143 | 0 | 107 | 36 | 0 | 250 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 0 | | | | | | | | | | | |
| 0 | | | | | | | | | | | | | | | |
| | 0 | 0 | | | | | | | | | | | | | |
| | 0 | 0 | | | | | | | | | | | | | |
| | 0 | 0 | | | | | | | | | | | | | |
| | 0 | 0 | 0 | 0 | | | | | | | | | | | |
| | 0 | 0 | 0 | | 0 | 0 | | | | | | | | | |
| | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | | | | | |
| | | 0 | 0 | | 0 | | 0 | 0 | 0 | 0 | | | | | |
| | | | | | | | | | | | 0 | | | | |
| | | | | | | | | | | | | 0 | | | |
| | | | | | | | | | | | 0 | | | | |
| | | | | | | | | | | | | 5 | 0 | | |
| | | | | | | | | | | | | 9 | 0 | | |
| | | | | | | | | | | | 0 | 0 | 0 | | |
| | | | | | | | | | | | | 0 | 0 | | |
| | 0 | | | | | | | | | | 0 | | | 40000 | |
| | | | | | | | | | | | 0 | | | 87657 | |
| | | | | | | | | | | | 0 | | | 29930 | |
| | | | | | | | | | | | 0 | | | | |
| | | | | | | 0 | | | | | | | | | 0 |
| | | | | | | 0 | | | | | | | | | 0 |
| | | | | | | 0 | | | | | | | | | 0 |
| | | | | | | 0 | | | | | | | | | |
| | | | | | | 0 | | | | | | | | | |
| | | | | | | 0 | | | | | | | | | |
| | | | | | | 0 | | | | | | | | | |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | | | | | | | | | | | | | | | 250 | | |
| | 0 | | | | | | | | | | | | | | | | | |
| | 0 | | | | | | | | | | | | | | | | | |
| | 0 | | | 0 | | 0 | | | | | | | | | | | | |
| | | | | 0 | | 0 | | | | | | | | | | | 0 | |
| | | | | 0 | | 0 | | | | | | | | | | | 0 | |
| | | | | | | | | | | | | | | | | | | 0 |
| | | | | | | | | | | | | | | | | | | 0 |
| | | | | | | | | | | | | | | | | | | 0 |
| | | | | | | | | | | | | | | | | | | 0 |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 250 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 40,000 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 87,657 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 0 | 29,930 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| OPERATOR | UNIT_NAME | STATE | YEAR | COAL (THOUSAND SH TONS) | ASH (%) | E X F |
|---|---|---|---|---|---|---|
| SOUTHERN INDIANA GAS ELEC | AB BROWN 1 | IN | 1993 | 470.4 | 7.96 | 3744.384 |
| SOUTHERN INDIANA GAS ELEC | AB BROWN 2 | IN | 1993 | 391.3 | 8.09 | 3165.617 |
| AMES MUNI ELEC SYSTEM | AMES TWO 7 | IA | 1993 | 40.1 | 4.47 | 179.247 |
| AMES MUNI ELEC SYSTEM | AMES TWO 8 | IA | 1993 | 154.5 | 4.45 | 687.525 |
| NO INDIANA PUBLIC SERVICE | BAILLY 7 | IN | 1993 | 492.8 | 10.15 | 5001.92 |
| NO INDIANA PUBLIC SERVICE | BAILLY 8 | IN | 1993 | 890.3 | 10.15 | 9036.545 |
| ILLINOIS POWER CO | BALDWIN 1 | IL | 1993 | 1394.4 | 9.34 | 13023.7 |
| ILLINOIS POWER CO | BALDWIN 2 | IL | 1993 | 1267.5 | 9.34 | 11838.45 |
| ILLINOIS POWER CO | BALDWIN 3 | IL | 1993 | 1432.6 | 9.34 | 13380.48 |
| INDIANA MICHIGAN POWER CO | BREED 1 | IN | 1993 | 17.1 | 11 | 188.1 |
| IOWA SOUTHERN UTILITIES | BURLINGTON (IA) 1 | IA | 1993 | 468.5 | 7.8 | 3654.3 |
| PSI ENERGY INC | CAYUGA 1 | IN | 1993 | 1170.3 | 9.51 | 11129.55 |
| PSI ENERGY INC | CAYUGA 2 | IN | 1993 | 1187.9 | 9.5 | 11285.05 |
| INDIANA KENTUCKY ELEC COR | CLIFTY CREEK 1 | IN | 1993 | 666.8 | 10.69 | 7128.092 |
| INDIANA KENTUCKY ELEC COR | CLIFTY CREEK 2 | IN | 1993 | 693.3 | 10.69 | 7411.377 |
| INDIANA KENTUCKY ELEC COR | CLIFTY CREEK 3 | IN | 1993 | 682.5 | 10.69 | 7295.925 |
| INDIANA KENTUCKY ELEC COR | CLIFTY CREEK 4 | IN | 1993 | 648.1 | 10.69 | 6928.189 |
| INDIANA KENTUCKY ELEC COR | CLIFTY CREEK 5 | IN | 1993 | 575.8 | 10.69 | 6155.302 |
| INDIANA KENTUCKY ELEC COR | CLIFTY CREEK 6 | IN | 1993 | 701 | 10.69 | 7493.69 |
| CENT ILLINOIS PUBLIC SERV | COFFEEN 1 | IL | 1993 | 523.2 | 9.39 | 4912.848 |
| CENT ILLINOIS PUBLIC SERV | COFFEEN 2 | IL | 1993 | 1152.3 | 9.44 | 10877.71 |
| MIDWEST POWER SYSTEMS | COUNCIL BLUFFS 1 | IA | 1993 | 205.2 | 4.64 | 952.128 |
| MIDWEST POWER SYSTEMS | COUNCIL BLUFFS 2 | IA | 1993 | 305 | 4.65 | 1418.25 |
| MIDWEST POWER SYSTEMS | COUNCIL BLUFFS 3 | IA | 1993 | 1876.8 | 4.5 | 8445.6 |
| COMMONWEALTH EDISON CO | CRAWFORD 7 | IL | 1993 | 226.7 | 5.51 | 1249.117 |
| COMMONWEALTH EDISON CO | CRAWFORD 8 | IL | 1993 | 590.5 | 5.67 | 3348.135 |
| CRAWFORDSVILLE ELEC LT PR | CRAWFORDSVILLE 5 | IN | 1993 | 11.32 | 8.19 | 92.7108 |
| SOUTHERN INDIANA GAS ELEC | CULLEY 1 | IN | 1993 | 61 | 8.33 | 508.13 |
| SOUTHERN INDIANA GAS ELEC | CULLEY 2 | IN | 1993 | 264.6 | 8.22 | 2175.012 |
| SOUTHERN INDIANA GAS ELEC | CULLEY 3 | IN | 1993 | 784 | 9.76 | 7651.84 |
| SPRINGFIELD WTR LT & PWR | DALLMAN 1 | IL | 1993 | 192.9 | 10.09 | 1946.361 |
| SPRINGFIELD WTR LT & PWR | DALLMAN 2 | IL | 1993 | 235.5 | 10.08 | 2373.84 |
| SPRINGFIELD WTR LT & PWR | DALLMAN 3 | IL | 1993 | 528.6 | 10.08 | 5328.288 |

| | | | | | | |
|---|---|---|---|---|---|---|
| NO INDIANA PUBLIC SERVICE | DH MITCHELL 11 | IN | 1993 | 269.1 | 5.89 | 1584.999 |
| NO INDIANA PUBLIC SERVICE | DH MITCHELL 4 | IN | 1993 | 107.5 | 5.82 | 625.65 |
| NO INDIANA PUBLIC SERVICE | DH MITCHELL 5 | IN | 1993 | 259.4 | 6.13 | 1590.122 |
| NO INDIANA PUBLIC SERVICE | DH MITCHELL 6 | IN | 1993 | 392.1 | 6.04 | 2368.284 |
| INTERSTATE POWER CO | DUBUQUE 2 | IA | 1993 | 0.9 | 10.91 | 9.819 |
| INTERSTATE POWER CO | DUBUQUE 3 | IA | 1993 | 25.3 | 10.91 | 276.023 |
| INTERSTATE POWER CO | DUBUQUE 4 | IA | 1993 | 51.5 | 10.91 | 561.865 |
| CENTRAL ILLINOIS LIGHT CO | DUCK CREEK 1 | IL | 1993 | 1044.8 | 8.21 | 8577.808 |
| CORN BELT POWER COOP | EARL F WISDOM 1 | IA | 1993 | 19 | 9.7 | 184.3 |
| JASPER MUNICIPAL UTIL | EAST FIFTEENTH ST 1 | IN | 1993 | 35.2 | 9.41 | 331.232 |
| CENTRAL ILLINOIS LIGHT CO | ED EDWARDS 1 | IL | 1993 | 119.8 | 5.95 | 712.81 |
| CENTRAL ILLINOIS LIGHT CO | ED EDWARDS 2 | IL | 1993 | 462.2 | 5.96 | 2754.712 |
| CENTRAL ILLINOIS LIGHT CO | ED EDWARDS 3 | IL | 1993 | 612.8 | 6.4 | 3921.92 |
| INDIANAPOLIS POWER & LT | EW STOUT 5 | IN | 1993 | 223.4 | 8.11 | 1811.774 |
| INDIANAPOLIS POWER & LT | EW STOUT 6 | IN | 1993 | 180.9 | 8.11 | 1467.099 |
| INDIANAPOLIS POWER & LT | EW STOUT 7 | IN | 1993 | 805.3 | 8.14 | 6555.142 |
| CENTRAL IOWA POWER COOP | FE FAIR 1 | IA | 1993 | 42.7 | 9.48 | 404.796 |
| CENTRAL IOWA POWER COOP | FE FAIR 2 | IA | 1993 | 83.7 | 9.46 | 791.802 |
| COMMONWEALTH EDISON CO | FISK 19 | IL | 1993 | 598.2 | 5.14 | 3074.748 |
| PSI ENERGY INC | GALLAGHER 1 | IN | 1993 | 301.77 | 8.66 | 2613.328 |
| PSI ENERGY INC | GALLAGHER 2 | IN | 1993 | 304.82 | 8.66 | 2639.741 |
| PSI ENERGY INC | GALLAGHER 3 | IN | 1993 | 262.04 | 8.63 | 2261.405 |
| PSI ENERGY INC | GALLAGHER 4 | IN | 1993 | 244.9 | 8.78 | 2150.222 |
| MIDWEST POWER SYSTEMS | GEORGE NEAL 1 | IA | 1993 | 443.3 | 6.29 | 2788.357 |
| MIDWEST POWER SYSTEMS | GEORGE NEAL 2 | IA | 1993 | 832.6 | 7.84 | 6527.584 |
| MIDWEST POWER SYSTEMS | GEORGE NEAL 3 | IA | 1993 | 1737.7 | 5.01 | 8705.877 |
| MIDWEST POWER SYSTEMS | GEORGE NEAL 4 | IA | 1993 | 2581.2 | 5.12 | 13215.74 |
| PSI ENERGY INC | GIBSON 1 | IN | 1993 | 1703.9 | 10.18 | 17345.7 |
| PSI ENERGY INC | GIBSON 2 | IN | 1993 | 1325.5 | 10.06 | 13334.53 |
| PSI ENERGY INC | GIBSON 3 | IN | 1993 | 1751.3 | 10.18 | 17828.23 |
| PSI ENERGY INC | GIBSON 4 | IN | 1993 | 1612.6 | 10.18 | 16416.27 |
| PSI ENERGY INC | GIBSON 5 | IN | 1993 | 1628.9 | 8.62 | 14041.12 |
| CENT ILLINOIS PUBLIC SERV | GRAND TOWER 3 | IL | 1993 | 19.3 | 11.83 | 228.319 |
| CENT ILLINOIS PUBLIC SERV | GRAND TOWER 4 | IL | 1993 | 132.3 | 11.76 | 1555.848 |

| | | | | | | |
|---|---|---|---|---|---|---|
| ILLINOIS POWER CO | HAVANA 6 | IL | 1993 | 569.7 | 8.75 | 4984.875 |
| ILLINOIS POWER CO | HENNEPIN 1 | IL | 1993 | 81.8 | 9.94 | 813.092 |
| ILLINOIS POWER CO | HENNEPIN 2 | IL | 1993 | 462.5 | 9.93 | 4592.625 |
| INDIANAPOLIS POWER & LT | HT PRITCHARD 3 | IN | 1993 | 28.6 | 7.51 | 214.786 |
| INDIANAPOLIS POWER & LT | HT PRITCHARD 4 | IN | 1993 | 68.4 | 7.5 | 513 |
| INDIANAPOLIS POWER & LT | HT PRITCHARD 5 | IN | 1993 | 69.7 | 7.5 | 522.75 |
| INDIANAPOLIS POWER & LT | HT PRITCHARD 6 | IN | 1993 | 210.6 | 7.5 | 1579.5 |
| CENT ILLINOIS PUBLIC SERV | HUTSONVILLE 3 | IL | 1993 | 112.1 | 9.62 | 1078.402 |
| CENT ILLINOIS PUBLIC SERV | HUTSONVILLE 4 | IL | 1993 | 99 | 9.57 | 947.43 |
| COMMONWEALTH EDISON CO | JOLIET 6 | IL | 1993 | 597.5 | 4.28 | 2557.3 |
| COMMONWEALTH EDISON CO | JOLIET 7 | IL | 1993 | 1225.3 | 5.64 | 6910.692 |
| COMMONWEALTH EDISON CO | JOLIET 8 | IL | 1993 | 657.3 | 5.74 | 3772.902 |
| ELECTRIC ENERGY INC | JOPPA 1 | IL | 1993 | 518.2 | 7.11 | 3684.402 |
| ELECTRIC ENERGY INC | JOPPA 2 | IL | 1993 | 623.2 | 7.11 | 4430.952 |
| ELECTRIC ENERGY INC | JOPPA 3 | IL | 1993 | 629.3 | 7.11 | 4474.323 |
| ELECTRIC ENERGY INC | JOPPA 4 | IL | 1993 | 557.5 | 7.11 | 3963.825 |
| ELECTRIC ENERGY INC | JOPPA 5 | IL | 1993 | 642 | 7.11 | 4564.62 |
| ELECTRIC ENERGY INC | JOPPA 6 | IL | 1993 | 672 | 7.11 | 4777.92 |
| COMMONWEALTH EDISON CO | KINCAID 1 | IL | 1993 | 772.6 | 9.25 | 7146.55 |
| COMMONWEALTH EDISON CO | KINCAID 2 | IL | 1993 | 1174.3 | 9.33 | 10956.22 |
| SPRINGFIELD WTR LT & PWR | LAKESIDE (IL) 6 | IL | 1993 | 38.5 | 10.17 | 391.545 |
| SPRINGFIELD WTR LT & PWR | LAKESIDE (IL) 7 | IL | 1993 | 39.9 | 10.09 | 402.591 |
| INTERSTATE POWER CO | LANSING 1 | IA | 1993 | 3.6 | 11.52 | 41.472 |
| INTERSTATE POWER CO | LANSING 2 | IA | 1993 | 3.6 | 11.52 | 41.472 |
| INTERSTATE POWER CO | LANSING 3 | IA | 1993 | 19.3 | 11.52 | 222.336 |
| INTERSTATE POWER CO | LANSING 4 | IA | 1993 | 529 | 4.64 | 2454.56 |
| LOGANSPORT MUNI UTIL | LOGANSPORT 4 | IN | 1993 | 33 | 6.79 | 224.07 |
| LOGANSPORT MUNI UTIL | LOGANSPORT 5 | IN | 1993 | 49 | 6.79 | 332.71 |
| IOWA-ILLINOIS GAS & ELEC | LOUISA 1 | IA | 1993 | 2157.7 | 4.99 | 10766.92 |
| SOUTH ILLINOIS POWER COOP | MARION (IL) 1 | IL | 1993 | 21 | 15.52 | 325.92 |
| SOUTH ILLINOIS POWER COOP | MARION (IL) 2 | IL | 1993 | 12 | 14.28 | 171.36 |
| SOUTH ILLINOIS POWER COOP | MARION (IL) 3 | IL | 1993 | 13 | 14.61 | 189.93 |
| SOUTH ILLINOIS POWER COOP | MARION (IL) 4 | IL | 1993 | 476 | 15.49 | 7373.24 |
| CENT ILLINOIS PUBLIC SERV | MEREDOSIA 1 | IL | 1993 | 10.8 | 6.62 | 71.496 |

| | | | | | | |
|---|---|---|---|---|---|---|
| CENT ILLINOIS PUBLIC SERV | MEREDOSIA 2 | IL | 1993 | 13.8 | 6.59 | 90.942 |
| CENT ILLINOIS PUBLIC SERV | MEREDOSIA 3 | IL | 1993 | 458.4 | 6.54 | 2997.936 |
| HOOSIER ENERGY REC | MEROM 1 | IN | 1993 | 1184.8 | 12.01 | 14229.45 |
| HOOSIER ENERGY REC | MEROM 2 | IN | 1993 | 1393.2 | 11.98 | 16690.54 |
| NO INDIANA PUBLIC SERVICE | MICHIGAN CITY 12 | IN | 1993 | 1373.1 | 7.76 | 10655.26 |
| INTERSTATE POWER CO | ML KAPP 2 | IA | 1993 | 510.1 | 7.59 | 3871.659 |
| MUSCATINE POWER & WATER | MUSCATINE 7 | IA | 1993 | 33.5 | 9.82 | 328.97 |
| MUSCATINE POWER & WATER | MUSCATINE 8 | IA | 1993 | 80.6 | 10 | 806 |
| MUSCATINE POWER & WATER | MUSCATINE 9 | IA | 1993 | 537.3 | 6.65 | 3573.045 |
| CENT ILLINOIS PUBLIC SERV | NEWTON 1 | IL | 1993 | 1195.2 | 11.01 | 13159.15 |
| CENT ILLINOIS PUBLIC SERV | NEWTON 2 | IL | 1993 | 1360 | 9.27 | 12607.2 |
| IOWA SOUTHERN UTILITIES | OTTUMWA 1 | IA | 1993 | 2676.1 | 5.31 | 14210.09 |
| SOYLAND POWER COOP | PEARL 1 | IL | 1993 | 62.8 | 8.17 | 513.076 |
| PERU (IN) UTILITIES | PERU (IN) 2 | IN | 1993 | 1.18 | 9.37 | 11.0566 |
| INDIANAPOLIS POWER & LT | PETERSBURG 1 | IN | 1993 | 710.9 | 8.64 | 6142.176 |
| INDIANAPOLIS POWER & LT | PETERSBURG 2 | IN | 1993 | 1154.4 | 8.72 | 10066.37 |
| INDIANAPOLIS POWER & LT | PETERSBURG 3 | IN | 1993 | 1456.7 | 8.64 | 12585.89 |
| INDIANAPOLIS POWER & LT | PETERSBURG 4 | IN | 1993 | 1292.6 | 8.64 | 11168.06 |
| COMMONWEALTH EDISON CO | POWERTON 5 | IL | 1993 | 1161.9 | 4.79 | 5565.501 |
| COMMONWEALTH EDISON CO | POWERTON 6 | IL | 1993 | 1733.4 | 4.88 | 8458.992 |
| IOWA ELEC LIGHT & POWER | PRAIRIE CREEK 3 | IA | 1993 | 112.6 | 5.7 | 641.82 |
| IOWA ELEC LIGHT & POWER | PRAIRIE CREEK 4 | IA | 1993 | 417.9 | 5.7 | 2382.03 |
| HOOSIER ENERGY REC | RATTS 1 | IN | 1993 | 266.4 | 9.42 | 2509.488 |
| HOOSIER ENERGY REC | RATTS 2 | IN | 1993 | 320.4 | 9.43 | 3021.372 |
| IOWA-ILLINOIS GAS & ELEC | RIVERSIDE (IA) 5 | IA | 1993 | 152.4 | 9.26 | 1411.224 |
| NO INDIANA PUBLIC SERVICE | RM SCHAHFER 14 | IN | 1993 | 959.3 | 7.24 | 6945.332 |
| NO INDIANA PUBLIC SERVICE | RM SCHAHFER 15 | IN | 1993 | 938.3 | 8.25 | 7740.975 |
| NO INDIANA PUBLIC SERVICE | RM SCHAHFER 17 | IN | 1993 | 705.6 | 10.12 | 7140.672 |
| NO INDIANA PUBLIC SERVICE | RM SCHAHFER 18 | IN | 1993 | 694.9 | 10.21 | 7094.929 |
| INDIANA MICHIGAN POWER CO | ROCKPORT 1 | IN | 1993 | 4718.8 | 4.81 | 22697.43 |
| INDIANA MICHIGAN POWER CO | ROCKPORT 2 | IN | 1993 | 4842.8 | 4.86 | 23536.01 |
| COMMONWEALTH EDISON (IN) | STATE LINE 3 | IN | 1993 | 384.3 | 3.59 | 1379.637 |
| COMMONWEALTH EDISON (IN) | STATE LINE 4 | IN | 1993 | 406.4 | 4.4 | 1788.16 |
| CEDAR FALLS UTILITIES | STREETER 6 | IA | 1993 | 1.6 | 8.4 | 13.44 |

| | | | | | | |
|---|---|---|---|---|---|---|
| CEDAR FALLS UTILITIES | STREETER 7 | IA | 1993 | 23.2 | 8.55 | 198.36 |
| IOWA ELEC LIGHT & POWER | SUTHERLAND 1 | IA | 1993 | 69.9 | 4.07 | 284.493 |
| IOWA ELEC LIGHT & POWER | SUTHERLAND 2 | IA | 1993 | 73.2 | 4.07 | 297.924 |
| IOWA ELEC LIGHT & POWER | SUTHERLAND 3 | IA | 1993 | 215.5 | 4.07 | 877.085 |
| INDIANA MICHIGAN POWER CO | TANNERS CREEK 1 | IN | 1993 | 283.6 | 10.36 | 2938.096 |
| INDIANA MICHIGAN POWER CO | TANNERS CREEK 2 | IN | 1993 | 92.9 | 9.98 | 927.142 |
| INDIANA MICHIGAN POWER CO | TANNERS CREEK 3 | IN | 1993 | 164.4 | 10.48 | 1722.912 |
| INDIANA MICHIGAN POWER CO | TANNERS CREEK 4 | IN | 1993 | 1322.1 | 9.39 | 12414.52 |
| ILLINOIS POWER CO | VERMILION 1 | IL | 1993 | 111.2 | 11.8 | 1312.16 |
| ILLINOIS POWER CO | VERMILION 2 | IL | 1993 | 211.6 | 11.73 | 2482.068 |
| PSI ENERGY INC | WABASH RIVER 1 | IN | 1993 | 147.9 | 9.07 | 1341.453 |
| PSI ENERGY INC | WABASH RIVER 2 | IN | 1993 | 170.8 | 9.06 | 1547.448 |
| PSI ENERGY INC | WABASH RIVER 3 | IN | 1993 | 175.38 | 9.07 | 1590.697 |
| PSI ENERGY INC | WABASH RIVER 4 | IN | 1993 | 143.18 | 9.07 | 1298.643 |
| PSI ENERGY INC | WABASH RIVER 5 | IN | 1993 | 178.41 | 9.07 | 1618.179 |
| PSI ENERGY INC | WABASH RIVER 6 | IN | 1993 | 593.35 | 9.07 | 5381.685 |
| SOUTHERN INDIANA GAS ELEC | WARRICK 4 | IN | 1993 | 993.3 | 9.76 | 9694.608 |
| COMMONWEALTH EDISON CO | WAUKEGAN 6 | IL | 1993 | 181.4 | 4.81 | 872.534 |
| COMMONWEALTH EDISON CO | WAUKEGAN 7 | IL | 1993 | 740.7 | 5.31 | 3933.117 |
| COMMONWEALTH EDISON CO | WAUKEGAN 8 | IL | 1993 | 390.4 | 5.66 | 2209.664 |
| RICHMOND POWER & LIGHT | WHITEWATER VALLEY 1 | IN | 1993 | 94.2 | 9.81 | 924.102 |
| RICHMOND POWER & LIGHT | WHITEWATER VALLEY 2 | IN | 1993 | 202 | 9.81 | 1981.62 |
| COMMONWEALTH EDISON CO | WILL COUNTY 1 | IL | 1993 | 415 | 4.88 | 2025.2 |
| COMMONWEALTH EDISON CO | WILL COUNTY 2 | IL | 1993 | 458.2 | 4.57 | 2093.974 |
| COMMONWEALTH EDISON CO | WILL COUNTY 3 | IL | 1993 | 542.5 | 5.09 | 2761.325 |
| COMMONWEALTH EDISON CO | WILL COUNTY 4 | IL | 1993 | 1069.8 | 5.15 | 5509.47 |
| ILLINOIS POWER CO | WOOD RIVER (IL) 4 | IL | 1993 | 87.4 | 8.16 | 713.184 |
| ILLINOIS POWER CO | WOOD RIVER (IL) 5 | IL | 1993 | 683.1 | 8.22 | 5615.082 |
| TOTAL | | | | 96843.05 | 1353.45 | 745361 |
| AVERAGE | | | | | 8.303374233 | |
| WT. AVERAGE | | | | | 7.696587462 | |

| OPERATOR | UNIT_NAME | STATE | YEAR | COAL (THOUSAND SH TONS) | SULFUR (%) | E X F |
|---|---|---|---|---|---|---|
| SOUTHERN INDIANA GAS ELEC | AB BROWN 1 | IN | 1993 | 470.4 | 3.67 | 1726.368 |
| SOUTHERN INDIANA GAS ELEC | AB BROWN 2 | IN | 1993 | 391.3 | 3.69 | 1443.897 |
| AMES MUNI ELEC SYSTEM | AMES TWO 7 | IA | 1993 | 40.1 | 0.21 | 8.421 |
| AMES MUNI ELEC SYSTEM | AMES TWO 8 | IA | 1993 | 154.5 | 0.21 | 32.445 |
| NO INDIANA PUBLIC SERVICE | BAILLY 7 | IN | 1993 | 492.8 | 3 | 1478.4 |
| NO INDIANA PUBLIC SERVICE | BAILLY 8 | IN | 1993 | 890.3 | 2.97 | 2644.191 |
| ILLINOIS POWER CO | BALDWIN 1 | IL | 1993 | 1394.4 | 2.58 | 3597.552 |
| ILLINOIS POWER CO | BALDWIN 2 | IL | 1993 | 1267.5 | 2.58 | 3270.15 |
| ILLINOIS POWER CO | BALDWIN 3 | IL | 1993 | 1432.6 | 2.58 | 3696.108 |
| INDIANA MICHIGAN POWER CO | BREED 1 | IN | 1993 | 17.1 | 3.66 | 62.586 |
| IOWA SOUTHERN UTILITIES | BURLINGTON (IA) | IA | 1993 | 468.5 | 1.48 | 693.38 |
| PSI ENERGY INC | CAYUGA 1 | IN | 1993 | 1170.3 | 2.1 | 2457.63 |
| PSI ENERGY INC | CAYUGA 2 | IN | 1993 | 1187.9 | 2.11 | 2506.469 |
| INDIANA KENTUCKY ELEC COR | CLIFTY CREEK 1 | IN | 1993 | 666.8 | 3.28 | 2187.104 |
| INDIANA KENTUCKY ELEC COR | CLIFTY CREEK 2 | IN | 1993 | 693.3 | 3.28 | 2274.024 |
| INDIANA KENTUCKY ELEC COR | CLIFTY CREEK 3 | IN | 1993 | 682.5 | 3.28 | 2238.6 |
| INDIANA KENTUCKY ELEC COR | CLIFTY CREEK 4 | IN | 1993 | 648.1 | 3.28 | 2125.768 |
| INDIANA KENTUCKY ELEC COR | CLIFTY CREEK 5 | IN | 1993 | 575.8 | 3.28 | 1888.624 |
| INDIANA KENTUCKY ELEC COR | CLIFTY CREEK 6 | IN | 1993 | 701 | 3.28 | 2299.28 |
| CENT ILLINOIS PUBLIC SERV | COFFEEN 1 | IL | 1993 | 523.2 | 2.86 | 1496.352 |
| CENT ILLINOIS PUBLIC SERV | COFFEEN 2 | IL | 1993 | 1152.3 | 2.84 | 3272.532 |
| MIDWEST POWER SYSTEMS | COUNCIL BLUFFS | IA | 1993 | 205.2 | 0.31 | 63.612 |
| MIDWEST POWER SYSTEMS | COUNCIL BLUFFS | IA | 1993 | 305 | 0.31 | 94.55 |
| MIDWEST POWER SYSTEMS | COUNCIL BLUFFS | IA | 1993 | 1876.8 | 0.32 | 600.576 |
| COMMONWEALTH EDISON CO | CRAWFORD 7 | IL | 1993 | 226.7 | 0.43 | 97.481 |
| COMMONWEALTH EDISON CO | CRAWFORD 8 | IL | 1993 | 590.5 | 0.42 | 248.01 |
| CRAWFORDSVILLE ELEC LT P | CRAWFORDSVILL | IN | 1993 | 11.32 | 1.66 | 18.7912 |
| SOUTHERN INDIANA GAS ELEC | CULLEY 1 | IN | 1993 | 61 | 1.35 | 82.35 |
| SOUTHERN INDIANA GAS ELEC | CULLEY 2 | IN | 1993 | 264.6 | 1.35 | 357.21 |
| SOUTHERN INDIANA GAS ELEC | CULLEY 3 | IN | 1993 | 784 | 2.37 | 1858.08 |
| SPRINGFIELD WTR LT & PWR | DALLMAN 1 | IL | 1993 | 192.9 | 3.17 | 611.493 |
| SPRINGFIELD WTR LT & PWR | DALLMAN 2 | IL | 1993 | 235.5 | 3.19 | 751.245 |

| | | | | | | |
|---|---|---|---|---|---|---|
| SPRINGFIELD WTR LT & PWR | DALLMAN 3 | IL | 1993 | 528.6 | 3.19 | 1686.234 |
| NO INDIANA PUBLIC SERVICE | DH MITCHELL 11 | IN | 1993 | 269.1 | 0.39 | 104.949 |
| NO INDIANA PUBLIC SERVICE | DH MITCHELL 4 | IN | 1993 | 107.5 | 0.38 | 40.85 |
| NO INDIANA PUBLIC SERVICE | DH MITCHELL 5 | IN | 1993 | 259.4 | 0.4 | 103.76 |
| NO INDIANA PUBLIC SERVICE | DH MITCHELL 6 | IN | 1993 | 392.1 | 0.39 | 152.919 |
| INTERSTATE POWER CO | DUBUQUE 2 | IA | 1993 | 0.9 | 2.8 | 2.52 |
| INTERSTATE POWER CO | DUBUQUE 3 | IA | 1993 | 25.3 | 2.8 | 70.84 |
| INTERSTATE POWER CO | DUBUQUE 4 | IA | 1993 | 51.5 | 2.8 | 144.2 |
| CENTRAL ILLINOIS LIGHT CO | DUCK CREEK 1 | IL | 1993 | 1044.8 | 3.3 | 3447.84 |
| CORN BELT POWER COOP | EARL F WISDOM 1 | IA | 1993 | 19 | 2.75 | 52.25 |
| JASPER MUNICIPAL UTIL | EAST FIFTEENTH | IN | 1993 | 35.2 | 1.39 | 48.928 |
| CENTRAL ILLINOIS LIGHT CO | ED EDWARDS 1 | IL | 1993 | 119.8 | 1.03 | 123.394 |
| CENTRAL ILLINOIS LIGHT CO | ED EDWARDS 2 | IL | 1993 | 462.2 | 1.03 | 476.066 |
| CENTRAL ILLINOIS LIGHT CO | ED EDWARDS 3 | IL | 1993 | 612.8 | 1.03 | 631.184 |
| INDIANAPOLIS POWER & LT | EW STOUT 5 | IN | 1993 | 223.4 | 1.77 | 395.418 |
| INDIANAPOLIS POWER & LT | EW STOUT 6 | IN | 1993 | 180.9 | 1.77 | 320.193 |
| INDIANAPOLIS POWER & LT | EW STOUT 7 | IN | 1993 | 805.3 | 1.77 | 1425.381 |
| CENTRAL IOWA POWER COOP | FE FAIR 1 | IA | 1993 | 42.7 | 3.14 | 134.078 |
| CENTRAL IOWA POWER COOP | FE FAIR 2 | IA | 1993 | 83.7 | 3.16 | 264.492 |
| COMMONWEALTH EDISON CO | FISK 19 | IL | 1993 | 598.2 | 0.43 | 257.226 |
| PSI ENERGY INC | GALLAGHER 1 | IN | 1993 | 301.77 | 2.18 | 657.8586 |
| PSI ENERGY INC | GALLAGHER 2 | IN | 1993 | 304.82 | 2.18 | 664.5076 |
| PSI ENERGY INC | GALLAGHER 3 | IN | 1993 | 262.04 | 2.18 | 571.2472 |
| PSI ENERGY INC | GALLAGHER 4 | IN | 1993 | 244.9 | 2.14 | 524.086 |
| MIDWEST POWER SYSTEMS | GEORGE NEAL 1 | IA | 1993 | 443.3 | 0.43 | 190.619 |
| MIDWEST POWER SYSTEMS | GEORGE NEAL 2 | IA | 1993 | 832.6 | 0.47 | 391.322 |
| MIDWEST POWER SYSTEMS | GEORGE NEAL 3 | IA | 1993 | 1737.7 | 0.41 | 712.457 |
| MIDWEST POWER SYSTEMS | GEORGE NEAL 4 | IA | 1993 | 2581.2 | 0.39 | 1006.668 |
| PSI ENERGY INC | GIBSON 1 | IN | 1993 | 1703.9 | 1.43 | 2436.577 |
| PSI ENERGY INC | GIBSON 2 | IN | 1993 | 1325.5 | 1.42 | 1882.21 |
| PSI ENERGY INC | GIBSON 3 | IN | 1993 | 1751.3 | 1.43 | 2504.359 |
| PSI ENERGY INC | GIBSON 4 | IN | 1993 | 1612.6 | 1.43 | 2306.018 |
| PSI ENERGY INC | GIBSON 5 | IN | 1993 | 1628.9 | 2.89 | 4707.521 |

| | | | | | | |
|---|---|---|---|---|---|---|
| CENT ILLINOIS PUBLIC SERV | GRAND TOWER 3 | IL | 1993 | 19.3 | 2.81 | 54.233 |
| CENT ILLINOIS PUBLIC SERV | GRAND TOWER 4 | IL | 1993 | 132.3 | 2.81 | 371.763 |
| ILLINOIS POWER CO | HAVANA 6 | IL | 1993 | 569.7 | 0.6 | 341.82 |
| ILLINOIS POWER CO | HENNEPIN 1 | IL | 1993 | 81.8 | 2.64 | 215.952 |
| ILLINOIS POWER CO | HENNEPIN 2 | IL | 1993 | 462.5 | 2.64 | 1221 |
| INDIANAPOLIS POWER & LT | HT PRITCHARD 3 | IN | 1993 | 28.6 | 1.26 | 36.036 |
| INDIANAPOLIS POWER & LT | HT PRITCHARD 4 | IN | 1993 | 68.4 | 1.26 | 86.184 |
| INDIANAPOLIS POWER & LT | HT PRITCHARD 5 | IN | 1993 | 69.7 | 1.26 | 87.822 |
| INDIANAPOLIS POWER & LT | HT PRITCHARD 6 | IN | 1993 | 210.6 | 1.26 | 265.356 |
| CENT ILLINOIS PUBLIC SERV | HUTSONVILLE 3 | IL | 1993 | 112.1 | 2.19 | 245.499 |
| CENT ILLINOIS PUBLIC SERV | HUTSONVILLE 4 | IL | 1993 | 99 | 2.19 | 216.81 |
| COMMONWEALTH EDISON CO | JOLIET 6 | IL | 1993 | 597.5 | 0.38 | 227.05 |
| COMMONWEALTH EDISON CO | JOLIET 7 | IL | 1993 | 1225.3 | 0.47 | 575.891 |
| COMMONWEALTH EDISON CO | JOLIET 8 | IL | 1993 | 657.3 | 0.4 | 262.92 |
| ELECTRIC ENERGY INC | JOPPA 1 | IL | 1993 | 518.2 | 1.27 | 658.114 |
| ELECTRIC ENERGY INC | JOPPA 2 | IL | 1993 | 623.2 | 1.27 | 791.464 |
| ELECTRIC ENERGY INC | JOPPA 3 | IL | 1993 | 629.3 | 1.27 | 799.211 |
| ELECTRIC ENERGY INC | JOPPA 4 | IL | 1993 | 557.5 | 1.27 | 708.025 |
| ELECTRIC ENERGY INC | JOPPA 5 | IL | 1993 | 642 | 1.27 | 815.34 |
| ELECTRIC ENERGY INC | JOPPA 6 | IL | 1993 | 672 | 1.27 | 853.44 |
| COMMONWEALTH EDISON CO | KINCAID 1 | IL | 1993 | 772.6 | 3.72 | 2874.072 |
| COMMONWEALTH EDISON CO | KINCAID 2 | IL | 1993 | 1174.3 | 3.7 | 4344.91 |
| SPRINGFIELD WTR LT & PWR | LAKESIDE (IL) 6 | IL | 1993 | 38.5 | 3.22 | 123.97 |
| SPRINGFIELD WTR LT & PWR | LAKESIDE (IL) 7 | IL | 1993 | 39.9 | 3.21 | 128.079 |
| INTERSTATE POWER CO | LANSING 1 | IA | 1993 | 3.6 | 2.27 | 8.172 |
| INTERSTATE POWER CO | LANSING 2 | IA | 1993 | 3.6 | 2.27 | 8.172 |
| INTERSTATE POWER CO | LANSING 3 | IA | 1993 | 19.3 | 2.27 | 43.811 |
| INTERSTATE POWER CO | LANSING 4 | IA | 1993 | 529 | 0.34 | 179.86 |
| LOGANSPORT MUNI UTIL | LOGANSPORT 4 | IN | 1993 | 33 | 0.77 | 25.41 |
| LOGANSPORT MUNI UTIL | LOGANSPORT 5 | IN | 1993 | 49 | 0.77 | 37.73 |
| IOWA-ILLINOIS GAS & ELEC | LOUISA 1 | IA | 1993 | 2157.7 | 0.34 | 733.618 |
| SOUTH ILLINOIS POWER COOP | MARION (IL) 1 | IL | 1993 | 21 | 2.55 | 53.55 |
| SOUTH ILLINOIS POWER COOP | MARION (IL) 2 | IL | 1993 | 12 | 2.52 | 30.24 |

| | | | | | | |
|---|---|---|---|---|---|---|
| SOUTH ILLINOIS POWER COOP | MARION (IL) 3 | IL | 1993 | 13 | 2.57 | 33.41 |
| SOUTH ILLINOIS POWER COOP | MARION (IL) 4 | IL | 1993 | 476 | 2.63 | 1251.88 |
| CENT ILLINOIS PUBLIC SERV | MEREDOSIA 1 | IL | 1993 | 10.8 | 2.97 | 32.076 |
| CENT ILLINOIS PUBLIC SERV | MEREDOSIA 2 | IL | 1993 | 13.8 | 2.96 | 40.848 |
| CENT ILLINOIS PUBLIC SERV | MEREDOSIA 3 | IL | 1993 | 458.4 | 2.99 | 1370.616 |
| HOOSIER ENERGY REC | MEROM 1 | IN | 1993 | 1184.8 | 3.43 | 4063.864 |
| HOOSIER ENERGY REC | MEROM 2 | IN | 1993 | 1393.2 | 3.45 | 4806.54 |
| NO INDIANA PUBLIC SERVICE | MICHIGAN CITY 12 | IN | 1993 | 1373.1 | 1.59 | 2183.229 |
| INTERSTATE POWER CO | ML KAPP 2 | IA | 1993 | 510.1 | 1.97 | 1004.897 |
| MUSCATINE POWER & WATER | MUSCATINE 7 | IA | 1993 | 33.5 | 2.81 | 94.135 |
| MUSCATINE POWER & WATER | MUSCATINE 8 | IA | 1993 | 80.6 | 2.78 | 224.068 |
| MUSCATINE POWER & WATER | MUSCATINE 9 | IA | 1993 | 537.3 | 1.47 | 789.831 |
| CENT ILLINOIS PUBLIC SERV | NEWTON 1 | IL | 1993 | 1195.2 | 2.64 | 3155.328 |
| CENT ILLINOIS PUBLIC SERV | NEWTON 2 | IL | 1993 | 1360 | 0.54 | 734.4 |
| IOWA SOUTHERN UTILITIES | OTTUMWA 1 | IA | 1993 | 2676.1 | 0.35 | 936.635 |
| SOYLAND POWER COOP | PEARL 1 | IL | 1993 | 62.8 | 3.18 | 199.704 |
| PERU (IN) UTILITIES | PERU (IN) 2 | IN | 1993 | 1.18 | 2.28 | 2.6904 |
| INDIANAPOLIS POWER & LT | PETERSBURG 1 | IN | 1993 | 710.9 | 2.5 | 1777.25 |
| INDIANAPOLIS POWER & LT | PETERSBURG 2 | IN | 1993 | 1154.4 | 2.5 | 2886 |
| INDIANAPOLIS POWER & LT | PETERSBURG 3 | IN | 1993 | 1456.7 | 2.5 | 3641.75 |
| INDIANAPOLIS POWER & LT | PETERSBURG 4 | IN | 1993 | 1292.6 | 2.5 | 3231.5 |
| COMMONWEALTH EDISON CO | POWERTON 5 | IL | 1993 | 1161.9 | 0.32 | 371.808 |
| COMMONWEALTH EDISON CO | POWERTON 6 | IL | 1993 | 1733.4 | 0.31 | 537.354 |
| IOWA ELEC LIGHT & POWER | PRAIRIE CREEK 3 | IA | 1993 | 112.6 | 0.72 | 81.072 |
| IOWA ELEC LIGHT & POWER | PRAIRIE CREEK 4 | IA | 1993 | 417.9 | 0.72 | 300.888 |
| HOOSIER ENERGY REC | RATTS 1 | IN | 1993 | 266.4 | 3.03 | 807.192 |
| HOOSIER ENERGY REC | RATTS 2 | IN | 1993 | 320.4 | 2.94 | 941.976 |
| IOWA-ILLINOIS GAS & ELEC | RIVERSIDE (IA) 5 | IA | 1993 | 152.4 | 2.3 | 350.52 |
| NO INDIANA PUBLIC SERVICE | RM SCHAHFER 14 | IN | 1993 | 959.3 | 0.51 | 489.243 |
| NO INDIANA PUBLIC SERVICE | RM SCHAHFER 15 | IN | 1993 | 938.3 | 0.4 | 375.32 |
| NO INDIANA PUBLIC SERVICE | RM SCHAHFER 17 | IN | 1993 | 705.6 | 2.91 | 2053.296 |
| NO INDIANA PUBLIC SERVICE | RM SCHAHFER 18 | IN | 1993 | 694.9 | 2.93 | 2036.057 |
| INDIANA MICHIGAN POWER CO | ROCKPORT 1 | IN | 1993 | 4718.8 | 0.31 | 1462.828 |

| | | | | | | |
|---|---|---|---|---|---|---|
| INDIANA MICHIGAN POWER CO | ROCKPORT 2 | IN | 1993 | 4842.8 | 0.31 | 1501.268 |
| COMMONWEALTH EDISON (IN | STATE LINE 3 | IN | 1993 | 384.3 | 0.38 | 146.034 |
| COMMONWEALTH EDISON (IN | STATE LINE 4 | IN | 1993 | 406.4 | 0.4 | 162.56 |
| CEDAR FALLS UTILITIES | STREETER 6 | IA | 1993 | 1.6 | 2.77 | 4.432 |
| CEDAR FALLS UTILITIES | STREETER 7 | IA | 1993 | 23.2 | 2.09 | 48.488 |
| IOWA ELEC LIGHT & POWER | SUTHERLAND 1 | IA | 1993 | 69.9 | 1.01 | 70.599 |
| IOWA ELEC LIGHT & POWER | SUTHERLAND 2 | IA | 1993 | 73.2 | 1.01 | 73.932 |
| IOWA ELEC LIGHT & POWER | SUTHERLAND 3 | IA | 1993 | 215.5 | 1.01 | 217.655 |
| INDIANA MICHIGAN POWER CO | TANNERS CREEK | IN | 1993 | 283.6 | 0.69 | 195.684 |
| INDIANA MICHIGAN POWER CO | TANNERS CREEK | IN | 1993 | 92.9 | 0.7 | 65.03 |
| INDIANA MICHIGAN POWER CO | TANNERS CREEK | IN | 1993 | 164.4 | 0.7 | 115.08 |
| INDIANA MICHIGAN POWER CO | TANNERS CREEK | IN | 1993 | 1322.1 | 2.38 | 3146.598 |
| ILLINOIS POWER CO | VERMILION 1 | IL | 1993 | 111.2 | 2.22 | 246.864 |
| ILLINOIS POWER CO | VERMILION 2 | IL | 1993 | 211.6 | 2.21 | 467.636 |
| PSI ENERGY INC | WABASH RIVER 1 | IN | 1993 | 147.9 | 2.02 | 298.758 |
| PSI ENERGY INC | WABASH RIVER 2 | IN | 1993 | 170.8 | 2.03 | 346.724 |
| PSI ENERGY INC | WABASH RIVER 3 | IN | 1993 | 175.38 | 2.02 | 354.2676 |
| PSI ENERGY INC | WABASH RIVER 4 | IN | 1993 | 143.18 | 2.02 | 289.2236 |
| PSI ENERGY INC | WABASH RIVER 5 | IN | 1993 | 178.41 | 2.02 | 360.3882 |
| PSI ENERGY INC | WABASH RIVER 6 | IN | 1993 | 593.35 | 2.02 | 1198.567 |
| SOUTHERN INDIANA GAS ELEC | WARRICK 4 | IN | 1993 | 993.3 | 2.58 | 2562.714 |
| COMMONWEALTH EDISON CO | WAUKEGAN 6 | IL | 1993 | 181.4 | 0.35 | 63.49 |
| COMMONWEALTH EDISON CO | WAUKEGAN 7 | IL | 1993 | 740.7 | 0.37 | 274.059 |
| COMMONWEALTH EDISON CO | WAUKEGAN 8 | IL | 1993 | 390.4 | 0.37 | 144.448 |
| RICHMOND POWER & LIGHT | WHITEWATER VAL | IN | 1993 | 94.2 | 2.03 | 191.226 |
| RICHMOND POWER & LIGHT | WHITEWATER VAL | IN | 1993 | 202 | 2.03 | 410.06 |
| COMMONWEALTH EDISON CO | WILL COUNTY 1 | IL | 1993 | 415 | 0.31 | 128.65 |
| COMMONWEALTH EDISON CO | WILL COUNTY 2 | IL | 1993 | 458.2 | 0.31 | 142.042 |
| COMMONWEALTH EDISON CO | WILL COUNTY 3 | IL | 1993 | 542.5 | 0.33 | 179.025 |
| COMMONWEALTH EDISON CO | WILL COUNTY 4 | IL | 1993 | 1069.8 | 0.32 | 342.336 |
| ILLINOIS POWER CO | WOOD RIVER (IL) | IL | 1993 | 87.4 | 0.68 | 59.432 |
| ILLINOIS POWER CO | WOOD RIVER (IL) | IL | 1993 | 683.1 | 0.69 | 471.339 |

| | | | |
|---|---|---|---|
| TOTAL | 96843.05 | 291.93 | 148593.7904 |
| AVERAGE | | 1.79 | |
| WT. AVERAGE | | 1.53 | |

Sheet Title: Acetonitrile and acrylonitrile production

Sheet Description:
Emissions are from TRI database.
Engineering calculation of the Energy requirements and precursor requirements .
This page calculates the vendor emissions from a plant producing PCl3.
Not included are raw material production or extraction or water use.

References/Citations:

Faith Keyes and Clarke's Industrial Chemicals
By F. A. Lowenheim, M. K. Moran
Wiley Interscience, 1975

Perry's Chemical Engineers' Handbook, 6th ed.
McGraw Hill, 1984

AP 42 Ed 4 (1985)
US EPA

SRI Directory of Chemical Producers, US
1993, 1991 editions
SRI International, Menlo Park, CA

US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993
US International Trade Commission, 11.1994

CRC Handbook of Chemistry and Physics, 66th Edition

Summary Output

Co-product Allocation Calculations

Source:
US ITC 2810 Synthetic Organic Chemicals US production and Sales, 1993
US International Trade Commission, 11.1994

| Mwt | Co-product | Quantity | Units | Quantity | Units | 1993 Production |
|---|---|---|---|---|---|---|
| 53.06 | Acetonitrile | 1.58E-02 | kg | 1.00E+00 | kg | 17,859.00 |
| 41.0524 | Acrylonitrile | 1.00E+00 | kg | 6.32E+01 | kg | 1,129,082.00 |
| 27.0256 | HCN to Acetone cyanoh | 2.12E-01 | kg | 1.34E+01 | kg | 239,876.00 |
| | | | | | | 1,240,744.98 |
| | Total | 1.23 | Kg | 7.77E+01 | Kg | |
| | | | | | | As acetone cyanoh |

Notes:

| LCI components | Unallocated Units | Quantity | Std. Dev. | Allocated Units | Quantity |
|---|---|---|---|---|---|
| **Air** | | | | | |
| Cl2 | Kg/kg Acrylonitrile | 1.63642E-06 | | Kg/kg Acetonit | 1.3323E-06 |
| Acetonitrile | Kg/kg Acrylonitrile | 7.67072E-06 | | Kg/kg Acetonit | 6.24514E-06 |
| Acrolein | Kg/kg Acrylonitrile | 1.50005E-07 | | Kg/kg Acetonit | 1.22127E-07 |
| Acrylic acid | Kg/kg Acrylonitrile | 5.11381E-09 | | Kg/kg Acetonit | 4.16343E-09 |
| Acrylonitrile | Kg/kg Acrylonitrile | 5.52292E-05 | | Kg/kg Acetonit | 4.4965E-05 |
| ammonia | Kg/kg Acrylonitrile | 1.44891E-05 | | Kg/kg Acetonit | 1.17964E-05 |
| Hydrogen Cyanide | Kg/kg Acrylonitrile | 8.21619E-05 | | Kg/kg Acetonit | 6.68924E-05 |
| Propylene | Kg/kg Acrylonitrile | 2.82964E-05 | | Kg/kg Acetonit | 2.30376E-05 |
| acetamide | Kg/kg Acrylonitrile | 1.7046E-08 | | Kg/kg Acetonit | 1.38781E-08 |
| acetaldehyde | Kg/kg Acrylonitrile | 6.64795E-08 | | Kg/kg Acetonit | 5.41246E-08 |
| Acrylamide | Kg/kg Acrylonitrile | 3.80127E-07 | | Kg/kg Acetonit | 3.09481E-07 |
| Pyridine | Kg/kg Acrylonitrile | 2.591E-07 | | Kg/kg Acetonit | 2.10947E-07 |
| HC total | Kg/kg Acrylonitrile | 0.000188725 | | Kg/kg Acetonit | 0.000153651 |
| **Water** | | | | | |
| ammonia | Kg/kg Acrylonitrile | 4.94335E-07 | | Kg/kg Acetonit | 4.02465E-07 |
| **Solid Wastes** | | | | | |
| Acetonitrile | Kg/kg Acrylonitrile | 5.11381E-09 | | Kg/kg Acetonit | 4.16343E-09 |
| Acrylonitrile | Kg/kg Acrylonitrile | 8.52302E-09 | | Kg/kg Acetonit | 6.93905E-09 |

| | | | | | |
|---|---|---|---|---|---|
| **Shipped out** | total | Kg/kg Acrylonitrile | 3.74655E-05 | Kg/kg Acetonit | 3.05027E-05 |
| | Acetonitrile | Kg/kg Acrylonitrile | 5.79565E-07 | Kg/kg Acetonit | 4.71855E-07 |
| | Acrolein | Kg/kg Acrylonitrile | 1.36368E-08 | Kg/kg Acetonit | 1.11025E-08 |
| | Acrylic acid | Kg/kg Acrylonitrile | 2.04552E-07 | Kg/kg Acetonit | 1.66537E-07 |
| | Acrylonitrile | Kg/kg Acrylonitrile | 6.30703E-08 | Kg/kg Acetonit | 5.13489E-08 |
| | ammonia | Kg/kg Acrylonitrile | 3.57967E-05 | Kg/kg Acetonit | 2.9144E-05 |
| | Molybdenum Trioxide | Kg/kg Acrylonitrile | 3.23875E-05 | Kg/kg Acetonit | 2.63684E-05 |
| | acetamide | Kg/kg Acrylonitrile | 1.67051E-07 | Kg/kg Acetonit | 1.36005E-07 |
| | acetaldehyde | Kg/kg Acrylonitrile | 2.55691E-08 | Kg/kg Acetonit | 2.08171E-08 |
| | Acrylamide | Kg/kg Acrylonitrile | 5.96611E-07 | Kg/kg Acetonit | 4.85733E-07 |
| | Pyridine | Kg/kg Acrylonitrile | 1.87506E-08 | Kg/kg Acetonit | 1.52659E-08 |
| | LCI component | Kg/kg Acrylonitrile | 0.006477494 | Kg/kg Acetonit | 0.005273675 |
| | Acetonitrile | Kg/kg Acrylonitrile | 7.84118E-08 | Kg/kg Acetonit | 6.38392E-08 |
| | Acrolein | Kg/kg Acrylonitrile | 0.000272737 | Kg/kg Acetonit | 0.000222049 |
| | Acrylic acid | Kg/kg Acrylonitrile | 0.001056854 | Kg/kg Acetonit | 0.000860442 |
| | Acrylonitrile | Kg/kg Acrylonitrile | 0.023864452 | Kg/kg Acetonit | 0.019429329 |
| | Propylene | Kg/kg Acrylonitrile | 9.37532E-05 | Kg/kg Acetonit | 7.63295E-05 |
| | Molybdenum Trioxide | Kg/kg Acrylonitrile | 0.00015171 | Kg/kg Acetonit | 0.000123515 |
| | acetamide | Kg/kg Acrylonitrile | 1.00572E-05 | Kg/kg Acetonit | 8.18807E-06 |
| | acetaldehyde | Kg/kg Acrylonitrile | 0.001585281 | Kg/kg Acetonit | 0.001290663 |
| | Acrylamide | Kg/kg Acrylonitrile | 0.000136368 | Kg/kg Acetonit | 0.000111025 |
| | **Resource Consumption** | | | | |
| | Heat Energy (fossil fuel) | MJ/kg Acrylonitrile | 1.100482758 | MJ/kg Acetonit | 0.895961957 |
| | Electric Power | MJ/kg Acrylonitrile | 5.78119E-07 | MJ/kg Acetonit | 4.70677E-07 |
| | ammonia | Kg/kg Acrylonitrile | 0.475 | Kg/kg Acetonit | 0.386722942 |
| | propylene | Kg/kg Acrylonitrile | 1.175 | Kg/kg Acetonit | 0.956630435 |

Notes: This section is where the project specfic calculations take place. Information on LCI components from below is co-product allocation scheme applied. It may be necessary to preface this section with a section detailing the c rules or calculations.

Data Quality Indicators (DQI) range from 5 as highest to 1 as lowest.  A value of 0 is used when no indicator wa

Conversion Factors

| Unit from | Unit to | Multiplier | Reference | |
|---|---|---|---|---|
| BTU | J | 1055.056 | CRC, 66th Edition | |
| Wh | J | 3600 | CRC, 66th Edition | |
| bbl CrO | BTU CrO | 5800000 | Chemical Engineers' Handbook, 6th ed. | |
| bbl | gal | 42 | Chemical Engineers' Handbook, 6th ed. | |
| gal diesel | BTU diesel | 118500 | Chemical Engineers' Handbook, 6th ed., Figure 9-4 @ S.G. = .76 | |
| gal | L | 3.785412 | CRC, 66th Edition | |
| kg | lb | 2.2046226 | CRC, 66th Edition | |
| yr | day | 365 | | |
| m^3 | bbl (petroleum) | 6.289811 | CRC, 66th Edition | |
| gal CrO | lb CrO | 7.2 | | |
| ton | lb | 2000 | | |
| gal fuel oil | BTU fuel oil | 138000 | | |
| cu. ft NG | BTU NG | 1032 | Chemical Engineers' Handbook, 6th ed. | |
| lb Coal (dry | BTU Coal | 12000 | calculation page B | SD=11% |
| kg NG | MJ NG | 46 | Calculated page C | SD=13% |

| | | | | | |
|---|---|---|---|---|---|
| Mw Benzen | 78.1134 | molar | | | |
| Mw Chlorin | 70.9 | dry air composition | | Mwt | mass composition |
| Mw ClBz | 112.56 | N2 | 0.78084 | 28.0134 | 0.75521 |
| Mw Cl2Bz | 147.01 | O2 | 0.20946 | 31.9988 | 0.231406 |
| Mw HCl | 36.4609 | CO2 | 0.00033 | 44.01 | 0.000501 |
| Mw NaOH 39.9971 | | Ar | 0.00934 | 39.948 | 0.012882 |
| | | total | 0.99997 | 28.96409 | 1 |

Ideal gas density at 15 C (60 F) — air (dry)

0.042296 mol/liter — 42.29634021 mol/m^3 — 1.225075005 kg/m^3

Calculations

**Acrylonitrile (and acetonitrile) Production** 1993

Source: US Chemical Industry Statistical Handbook 1994
Chemical Manufacturers Association, Washington DC

| | | | |
|---|---|---|---|
| m ton | 1,129,082.00 | Mlb | 2489.174177 |

**MEK production capacity**

Source: SRI 1991 Directory of Chemical Producers, US

| | | |
|---|---|---|
| | Mlb | 3055 |
| Utilization ratio: | | 0.814786965 |
| BP Chemicals, Inc. Green Lake @ PMlb | | 720 |
| at Port Lavaca TX 77979 | | |
| Calculated production: | | 586.6466146 |

Source: Emissions:
TRI database, 1993 data
The Green Lake plant of BP produces acrylonitrile from propylene and some by products including hydrogen cyanide.

The following reported emissions were deemed unrelated to 'nitrile production: Acetone diethanolamine
Emissions allocated between the products = Acetonitrile Acrolein

Co-Products: Given above.

**Resources:**

| **Energy input**<br>LCI component | Raw/<br>Input Units | Raw/<br>Input Quan. | Raw/<br>Input Std. Dev. | DQI | Transformed<br>Units |
|---|---|---|---|---|---|
| Fossil fuel (general) | MJ/kg Acrylonitrile | 1.100482758 | | | MJ/Kg Acrylonitrile |
| Coal | MJ/kg Acrylonitrile | 0 | | | Kg/kg Acrylonitrile |
| Oil | MJ/kg Acrylonitrile | 0 | 15 | | Kg/kg Acrylonitrile |
| Natural Gas | MJ/kg Acrylonitrile | 0 | | | Kg/kg Acrylonitrile |
| Hydropower | MJ/kg Acrylonitrile | 0 | | | |
| Fission | MJ/kg Acrylonitrile | 0 | | | |
| Electricity (generic) | MJ/kg Acrylonitrile | 5.78119E-07 | | | MJ/Kg Acrylonitrile |

Energy requirement

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | Cal/mol | |
| Heat | Distillation columns | 3 prod is light end | | Evaporate acrylonitrile once | | 7941.4 |
| | | 1 bottomsproduct | | Evaporate acetonitrile twice | | 16348.4 |
| | | | | 10% loss as bottoms | | 794.14 |
| | | | | cal/gr | MJ/Kg | |
| | | | | Cooling water | 25 | 0.1027 |

| | | | | | |
|---|---|---|---|---|---|
| | | | Coolers: flow | | General flow |
| | | | Kg | Material | Kg/Kg Acrylonitrile |
| Electricity | 9 minimum pumping stations + 4 coolers | Pump 1 Kg | 2.67887721 | Acrylonitrile | 1.00E+00 |
| | | | | Acetonitrile | 1.58E-02 |
| | | | | HCN/Acetonitri | 0.456539029 |

7.8726E-08 MJ Elec/Kg Based on viscosity and density of water for a 250 ft static head per pumping stage in 40hr week & 52 week year daytime operation. multiply by specific gravity of material and relative viscosity to that of water.

source: Faith Keyes and Clarke's Industrial Chemicals 4th Ed 1975

**Material input**

| LCI component | | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units |
|---|---|---|---|---|---|---|
| Oil | | Kg/kg Acrylonitrile | 0 | | 4 | Kg/kg Acrylonitrile |
| Natural Gas | | Kg/kg Acrylonitrile | 0 | | 4 | Kg/kg Acrylonitrile |
| Coal | | Kg/kg Acrylonitrile | 0 | | 4 | Kg/kg Acrylonitrile |
| Naphtha | | Kg/kg Acrylonitrile | 0 | | 4 | Kg/kg Acrylonitrile |
| ammonia | | Kg/kg Acrylonitrile | 0.475 | | 4 | Kg/kg Acrylonitrile |
| propylene | | Kg/kg Acrylonitrile | 1.175 | | 4 | Kg/kg Acrylonitrile |
| Air | | Kg/kg Acrylonitrile | 0 | | 4 | Kg/kg Acrylonitrile |
| Water | steam | Kg/kg Acrylonitrile | 0 | | 4 | Kg/kg Acrylonitrile |

**Air**

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units |
|---|---|---|---|---|---|
| TSP | lb/BP Green Lake | 0 | | | Kg/kg Acrylonitrile |
| SOx | lb/BP Green Lake | 0 | | | Kg/kg Acrylonitrile |
| NOx | lb/BP Green Lake | 0 | | | Kg/kg Acrylonitrile |
| Cl2 | lb/BP Green Lake | 960 | | | Kg/kg Acrylonitrile |
| CO2 | lb/BP Green Lake | 0 | | 3 | Kg/kg Acrylonitrile |
| P4 | lb/BP Green Lake | 0 | | | Kg/kg Acrylonitrile |
| Acetonitrile | lb/BP Green Lake | 4500 | | | Kg/kg Acrylonitrile |
| Acrolein | lb/BP Green Lake | 88 | | | Kg/kg Acrylonitrile |
| Acrylic acid | lb/BP Green Lake | 3 | | | Kg/kg Acrylonitrile |
| Acrylonitrile | lb/BP Green Lake | 32400 | | | Kg/kg Acrylonitrile |
| ammonia | lb/BP Green Lake | 8500 | | | Kg/kg Acrylonitrile |
| Hydrogen Cyanide | lb/BP Green Lake | 48200 | | | Kg/kg Acrylonitrile |
| Propylene | lb/BP Green Lake | 16600 | | | Kg/kg Acrylonitrile |
| Molybdenum Trioxide | lb/BP Green Lake | 0 | | | Kg/kg Acrylonitrile |
| acetamide | lb/BP Green Lake | 10 | | | Kg/kg Acrylonitrile |
| acetaldehyde | lb/BP Green Lake | 39 | | | Kg/kg Acrylonitrile |
| Acrylamide | lb/BP Green Lake | 223 | | | Kg/kg Acrylonitrile |
| Pyridine | lb/BP Green Lake | 152 | | | Kg/kg Acrylonitrile |
| HC total | lb/BP Green Lake | 110715 | | | Kg/kg Acrylonitrile |
| Heavy meta(Cd+Ni+Cr) | lb/BP Green Lake | 0 | | | Kg/kg Acrylonitrile |

**Water**

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units |
|---|---|---|---|---|---|
| COD | lb/BP Green Lake | 0 | | 5 | Kg/kg Acrylonitrile |
| BOD | lb/BP Green Lake | 0 | | 5 | Kg/kg Acrylonitrile |
| Acid, H+ (Phosphoric) | lb/BP Green Lake | 0 | | 5 | Kg/kg Acrylonitrile |
| Metal ions | lb/BP Green Lake | 0 | | 5 | Kg/kg Acrylonitrile |
| Cl2 | lb/BP Green Lake | 0 | | 5 | Kg/kg Acrylonitrile |
| Acetonitrile | lb/BP Green Lake | 0 | | 5 | Kg/kg Acrylonitrile |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Acrolein | lb/BP Green Lake | 0 | | 5 | Kg/kg Acrylonitrile |
| | Acrylic acid | lb/BP Green Lake | 0 | | 5 | Kg/kg Acrylonitrile |
| | Acrylonitrile | lb/BP Green Lake | 0 | | 5 | Kg/kg Acrylonitrile |
| | ammonia | lb/BP Green Lake | 290 | | 5 | Kg/kg Acrylonitrile |
| | Hydrogen Cyanide | lb/BP Green Lake | 0 | | | Kg/kg Acrylonitrile |
| | Propylene | lb/BP Green Lake | 0 | | | Kg/kg Acrylonitrile |
| | Molybdenum Trioxide | lb/BP Green Lake | 0 | | | Kg/kg Acrylonitrile |
| | acetamide | lb/BP Green Lake | 0 | | | Kg/kg Acrylonitrile |
| | acetaldehyde | lb/BP Green Lake | 0 | | | Kg/kg Acrylonitrile |
| | Acrylamide | lb/BP Green Lake | 0 | | | Kg/kg Acrylonitrile |
| | Pyridine | lb/BP Green Lake | 0 | | | Kg/kg Acrylonitrile |

**Solid waste**

| | LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units |
|---|---|---|---|---|---|---|
| | Production waste (not innert) | lb/BP Green Lake | 0 | | 5 | Kg/kg Acrylonitrile |
| | Acetonitrile | lb/BP Green Lake | 3 | | | Kg/kg Acrylonitrile |
| | Acrylonitrile | lb/BP Green Lake | 5 | | 5 | Kg/kg Acrylonitrile |
| **Shipped out** | total no catalyst | lb/BP Green Lake | 21979 | | 5 | Kg/kg Acrylonitrile |
| | Acetonitrile | lb/BP Green Lake | 340 | | 5 | Kg/kg Acrylonitrile |
| | Acrolein | lb/BP Green Lake | 8 | | 5 | Kg/kg Acrylonitrile |
| | Acrylic acid | lb/BP Green Lake | 120 | | 5 | Kg/kg Acrylonitrile |
| | Acrylonitrile | lb/BP Green Lake | 37 | | 5 | Kg/kg Acrylonitrile |
| | ammonia | lb/BP Green Lake | 21000 | | 5 | Kg/kg Acrylonitrile |
| | Hydrogen Cyanide | lb/BP Green Lake | 0 | | 5 | Kg/kg Acrylonitrile |
| | Propylene | lb/BP Green Lake | 0 | | 5 | Kg/kg Acrylonitrile |
| To recycle | Molybdenum Trioxide | lb/BP Green Lake | *19000* | | 5 | Kg/kg Acrylonitrile |
| | acetamide | lb/BP Green Lake | 98 | | | Kg/kg Acrylonitrile |
| | acetaldehyde | lb/BP Green Lake | 15 | | | Kg/kg Acrylonitrile |
| | Acrylamide | lb/BP Green Lake | 350 | | | Kg/kg Acrylonitrile |
| | Pyridine | lb/BP Green Lake | 11 | | | Kg/kg Acrylonitrile |

| | | | | | |
|---|---|---|---|---|---|
| Heavy metals (Cadmium, Nickel, CHb/BP Green Lake | | 0 | | | 5 Kg/kg Acrylonitrile |

**Deep well injection**

| LCI component | Raw/ Input Units | Raw/ Input Quan. | Raw/ Input Std. Dev. | DQI | Transformed Units |
|---|---|---|---|---|---|
| Acetonitrile | lb/BP Green Lake | 3,800,000.00 | | | Kg/kg Acrylonitrile |
| Acrolein | lb/BP Green Lake | 46 | | | Kg/kg Acrylonitrile |
| Acrylic acid | lb/BP Green Lake | 160000 | | | Kg/kg Acrylonitrile |
| Acrylonitrile | lb/BP Green Lake | 620000 | | | Kg/kg Acrylonitrile |
| ammonia | lb/BP Green Lake | 14000000 | | | Kg/kg Acrylonitrile |
| Hydrogen Cyanide | lb/BP Green Lake | 0 | | | Kg/kg Acrylonitrile |
| Propylene | lb/BP Green Lake | 0 | | | Kg/kg Acrylonitrile |
| Molybdenum Trioxide | lb/BP Green Lake | 55000 | | | Kg/kg Acrylonitrile |
| acetamide | lb/BP Green Lake | 89000 | | | Kg/kg Acrylonitrile |
| acetaldehyde | lb/BP Green Lake | 5900 | | | Kg/kg Acrylonitrile |
| Acrylamide | lb/BP Green Lake | 930000 | | | Kg/kg Acrylonitrile |
| Pyridine | lb/BP Green Lake | 80000 | | | Kg/kg Acrylonitrile |

Sheet End ======== ================= =============== ============ ========== ========== =============

| | | | | |
|---|---|---|---|---|
| | 336.5812288 | | 17859 | 0.014394 |
| 720 | 27503.43463 | | 1129082 | 0.910003 |
| 60 | 3470.930401 | 69.11 | 93803.98 | 0.075603 |

| | |
|---|---|
| hydrin | 60 |

| Std. Dev. | DQI |
|---|---|
| | 3 |
| | 3 |
| | 3 |
| | 3 |

taken and the proper
o-product allocation

as reported.

--------------------- ------------------

and sulfur = 0.5%

kg air per kg
component
1.324134
4.321406
1994.319
77.62792

--------------------- ------------------

| | | | | | | |
|---|---|---|---|---|---|---|
| Cyanide compour | Hydroquinone | Formaldehyde | methanol | Chlorine | Benzene | |
| Acrylic acid | Acrylonitrile | ammonia | Hydrogen Cyanide | | Propylene | Molybdenum |

| Transformed Quan. | Transformed Std. Dev. |
|---|---|
| 1.100482758 | |
| 0 | |
| 0 | |
| 0 | |
| 0 | |
| 0 | |
| 5.78119E-07 | |

| MJ/kg Acrylonitrile | |
|---|---|
| 0.794673909 | |
| 0.288925823 | |
| 0.016883025 | |
| 1.100482758 | |
| 10.71550884 | Kg water |

| Sp Gr | Sp visc | numper of pumping stages | | Electric Demand | |
|---|---|---|---|---|---|
| 0.806 | 0.7 | Absorber, Separator, Colu | 5 | **2.22E-07** | |
| 0.7857 | 0.7 | condenser and storage | 2 | **1.37E-09** | |
| 1 | 2 | Absorber, Separator | 2 | **1.44E-07** | |
| | These are | | | | |
| | guesses | Coolers | | **2.11E-07** | |
| | | Total | | 5.78E-07 | MJ/Kg Acrylonitrile |

| Transformed Quan. | Transformed Std. Dev. | |
|---|---|---|
| 0 | | |
| 0 | | |
| 0 | | |
| 0 | | |
| 0.475 | | (all out into water emission) |
| 1.175 | | |
| 0 | | |
| 0 | | |

| Transformed Quan. | Transformed Std. Dev. |
|---|---|
| 0 | |
| 0 | |
| 0 | |
| 1.63642E-06 | |
| 0 | |
| 0 | |
| 7.67072E-06 | |
| 1.50005E-07 | |
| 5.11381E-09 | |
| 5.52292E-05 | |
| 1.44891E-05 | |
| 8.21619E-05 | |
| 2.82964E-05 | |
| 0 | |
| 1.7046E-08 | |
| 6.64795E-08 | |
| 3.80127E-07 | |
| 2.591E-07 | |
| 0.000188725 | |
| 0 | |

| Transformed Quan. | Transformed Std. Dev. |
|---|---|
| 0 | |
| 0 | |
| 0 | |
| 0 | |
| 0 | |
| 0 | |

| |
|---|
| 0 |
| 0 |
| 0 |
| 4.94335E-07 |
| 0 |
| 0 |
| 0 |
| 0 |
| 0 |
| 0 |
| 0 |

| Transformed Quan. | Transformed Std. Dev. |
|---|---|
| 0 | |
| 5.11381E-09 | |
| 8.52302E-09 | |
| 3.74655E-05 | |
| 5.79565E-07 | |
| 1.36368E-08 | |
| 2.04552E-07 | |
| 6.30703E-08 | |
| 3.57967E-05 | |
| 0 | |
| 0 | |
| 3.23875E-05 | |
| 1.67051E-07 | |
| 2.55691E-08 | |
| 5.96611E-07 | |
| 1.87506E-08 | |

0

| Transformed Quan. | Transformed Std. Dev. |
|---|---|
| 0.006477494 | |
| 7.84118E-08 | |
| 0.000272737 | |
| 0.001056854 | |
| 0.023864452 | |
| 0 | |
| 0 | |
| 9.37532E-05 | |
| 0.00015171 | |
| 1.00572E-05 | |
| 0.001585281 | |
| 0.000136368 | |

============ ========== ================== ======== ========

TABLE 1. INVENTORY FOR BASELINE PBXN-109 DEMILITARIZATION PROCESS
(All units in lb/bomb, except electricity in kwh/bomb)

| | | | HE Washout | | | Process |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | Total |
| PBXN-109 | (525.00) | 0.00 | 509.25 | 0.00 | 15.75 | 0 |
| TNAZ/Al | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Asphalt | (18.50) | 0.00 | 0.00 | 0.00 | 18.50 | 0 |
| Bomb Case | (1,390.00) | 0.00 | 0.00 | 0.00 | 1,390.00 | 0 |
| Potting | (3.00) | 0.00 | 0.00 | 0.00 | 3.00 | 0 |
| Felt Pad | ? | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Thermal Insulation | (25.00) | 0.00 | 0.00 | 0.00 | 25.00 | 0 |
| TCA (solvent) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Water | 0.00 | (63,050.40) | 0.00 | 63,050.40 | 0.00 | 0 |
| Steam | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Fuel | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Air | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Electricity, kwh/bomb | 0.00 | (1,738.00) | 0.00 | 0.00 | 0.00 | -1738 |
| Activated Carbon | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| CO | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| N2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| H2O | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| H2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| CO2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| H | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| HO | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| NO | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Al | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| O | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| CH4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| NH3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| C2H4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| C3H6 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| C2H6 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| C2H2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| C3H8 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| CHN | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| C | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Flue Gas | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Total gaseous pollutant | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Al2O3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Ash | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |

| | | | Burning Ground | | | Process |
|---|---|---|---|---|---|---|
| | 3 | 6 | 7 | 8 | 9 | Total |
| PBXN-109 | (0.00) | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| TNAZ/Al | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Asphalt | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Bomb Case | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Potting | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Felt Pad | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Thermal Insulation | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| TCA (solvent) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Water | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Steam | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Fuel | 0.00 ? | | 0.00 | 0.00 | 0.00 | 0 |
| Air | 0.00 | 0.00 ? | | 0.00 | 0.00 | 0 |
| Electricity, kwh/bomb | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Activated Carbon | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| CO | 0.00 | 0.00 | 0.00 ? | | 0.00 | 0 |
| N2 | 0.00 | 0.00 | 0.00 ? | | 0.00 | 0 |
| H2O | 0.00 | 0.00 | 0.00 ? | | 0.00 | 0 |
| H2 | 0.00 | 0.00 | 0.00 ? | | 0.00 | 0 |
| CO2 | 0.00 | 0.00 | 0.00 ? | | 0.00 | 0 |
| H | 0.00 | 0.00 | 0.00 ? | | 0.00 | 0 |
| HO | 0.00 | 0.00 | 0.00 ? | | 0.00 | 0 |
| NO | 0.00 | 0.00 | 0.00 ? | | 0.00 | 0 |
| Al | 0.00 | 0.00 | 0.00 ? | | 0.00 | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| O | 0.00 | 0.00 | 0.00 ? | | 0.00 | 0 |
| CH4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| NH3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| C2H4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| C3H6 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| C2H6 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| C2H2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| C3H8 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| CHN | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| C | 0.00 | 0.00 | 0.00 | 0.00 | 52.38 | 52.38 |
| Flue Gas | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Total gaseous pollutant | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Al2O3 | 0.00 | 0.00 | 0.00 | 0.00 | 192.06 | 192.06 |
| Ash | 0.00 | 0.00 | 0.00 | 0.00 | 244.44 | 244.44 |

| | | | Wastewater Treatment | | Process | Solid | Wastewater |
|---|---|---|---|---|---|---|---|
| | 4 | 10 | 11 | 12 | Total | Wastes | Emissions |
| PBXN-109 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| TNAZ/Al | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Asphalt | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Bomb Case | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Potting | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Felt Pad | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Thermal Insulation | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| TCA (solvent) | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Water | 0.00 | 0.00 | 0.75 | 63,049.65 | 63050.4 | 0.752164 | 63049.648 |
| Steam | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Fuel | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Air | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Electricity, kwh/bomb | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Activated Carbon | 0.00 | (14.29) | 14.29 | 0.00 | 0 | 14.291115 | 0 |
| CO | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| N2 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| H2O | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| H2 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| CO2 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| H | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| HO | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| NO | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Al | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| O | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| CH4 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| NH3 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C2H4 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C3H6 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C2H6 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C2H2 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C3H8 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| CHN | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Flue Gas | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Total gaseous pollutant | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Al2O3 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Ash | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |

| | Solvent Soak | | | | Process |
|---|---|---|---|---|---|
| | 5 | 13 | 14 | 15 | Total |
| PBXN-109 | (15.75) | 0.00 | 15.75 | 0.00 | 0 |
| TNAZ/Al | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Asphalt | (18.50) | 0.00 | 18.50 | 0.00 | 0 |
| Bomb Case | (1,390.00) | 0.00 | 0.00 | 1,390.00 | 0 |
| Potting | (3.00) | 0.00 | 0.00 | 3.00 | 0 |
| Felt Pad | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Thermal Insulation | (25.00) | 0.00 | 0.00 | 25.00 | 0 |
| TCA (solvent) | 0.00 | (212.50) | 212.50 | 0.00 | 0 |
| Water | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Steam | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Fuel | 0.00 | 0.00 | 0.00 | 0.00 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| Air | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Electricity, kwh/bomb | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Activated Carbon | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| CO | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| N2 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| H2O | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| H2 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| CO2 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| H | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| HO | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| NO | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Al | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| O | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| CH4 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| NH3 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| C2H4 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| C3H6 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| C2H6 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| C2H2 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| C3H8 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| CHN | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| C | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Flue Gas | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Total gaseous pollutant | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Al2O3 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Ash | 0.00 | 0.00 | 0.00 | 0.00 | 0 |

| | Incinerator<br>14 | 16 | 17 | 18 | 19 | Process<br>Total | Air<br>Emissions | Solid<br>Wastes |
|---|---|---|---|---|---|---|---|---|
| PBXN-109 | -15.75 | 0.00 | 0.00 | 0.00 | 0.00 | -15.75 | 0 | 0 |
| TNAZ/Al | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Asphalt | -18.5 | 0.00 | 0.00 | 0.00 | 0.00 | -18.5 | 0 | 0 |
| Bomb Case | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Potting | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Felt Pad | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Thermal Insulation | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| TCA (solvent) | -212.5 | 0.00 | 0.00 | 0.00 | 0.00 | -212.5 | 0 | 0 |
| Water | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Steam | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Fuel | 0 ? | | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Air | 0 | 0.00 ? | | 0.00 | 0.00 | 0 | 0 | 0 |
| Electricity, kwh/bomb | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Activated Carbon | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| CO | 0 | 0.00 | 0.00 ? | | 0.00 | 0 ? | | 0 |
| N2 | 0 | 0.00 | 0.00 ? | | 0.00 | 0 ? | | 0 |
| H2O | 0 | 0.00 | 0.00 ? | | 0.00 | 0 ? | | 0 |
| H2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| CO2 | 0 | 0.00 | 0.00 ? | | 0.00 | 0 ? | | 0 |
| H | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| HO | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| NO | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Al | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| O | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| CH4 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| NH3 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C2H4 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C3H6 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C2H6 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C2H2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C3H8 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| CHN | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Flue Gas | 0 | 0.00 | 0.00 ? | | 0.00 | 0 ? | | 0 |
| Total gaseous pollutant | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Al2O3 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Ash | 0 | 0.00 | 0.00 | 0.00 ? | | 0 | 0 ? | |
| | | | | | | Process | Solid | Recycle |

| | 15 | 20 | 21 | 22 | 23 | 24 | Total | Waste | Scrap |
|---|---|---|---|---|---|---|---|---|---|
| PBXN-109 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| TNAZ/Al | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Asphalt | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Bomb Case | -1390 | 0.00 | 0.00 | 0.00 | 0.00 | 1,390.00 | 0 | 0 | 1390 |
| Potting | -3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -3 | 0 | 0 |
| Felt Pad | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Thermal Insulation | -25 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -25 | 0 | 0 |
| TCA (solvent) | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Water | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Steam | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Fuel | 0 ? | | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Air | 0 | 0.00 ? | | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Electricity, kwh/bomb | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Activated Carbon | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| CO | 0 | 0.00 | 0.00 ? | | 0.00 | 0.00 | 0 | 0 | 0 |
| N2 | 0 | 0.00 | 0.00 ? | | 0.00 | 0.00 | 0 | 0 | 0 |
| H2O | 0 | 0.00 | 0.00 ? | | 0.00 | 0.00 | 0 | 0 | 0 |
| H2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| CO2 | 0 | 0.00 | 0.00 ? | | 0.00 | 0.00 | 0 | 0 | 0 |
| H | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| HO | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| NO | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Al | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| O | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| CH4 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| NH3 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C2H4 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C3H6 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C2H6 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C2H2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C3H8 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| CHN | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Flue Gas | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Total gaseous pollutant | 0 | 0.00 | 0.00 ? | | 0.00 | 0.00 | 0 | 0 | 0 |
| Al2O3 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Ash | 0 | 0.00 | 0.00 | 0.00 ? | | 0.00 | 0 ? | | 0 |

TABLE 2. INVENTORY FOR OPTION 1 PBXN-109 DEMILITARIZATION PROCESS
(All units in lb/bomb, except electricity in kwh/bomb)

| | HE Removal | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| PBXN-109 | (525.00) | 0.00 | 509.25 | 0.00 | 15.75 |
| TNAZ/Al | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Asphalt | (18.50) | 0.00 | 0.00 | 0.00 | 18.50 |
| Bomb Case | (1,390.00) | 0.00 | 0.00 | 0.00 | 1,390.00 |
| Potting | (3.00) | 0.00 | 0.00 | 0.00 | 3.00 |
| Felt Pad | ? | 0.00 | 0.00 | 0.00 | 0.00 |
| Thermal Insulation | (25.00) | 0.00 | 0.00 | 0.00 | 25.00 |
| TCA (solvent) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Water | 0.00 | (63,050.40) | 0.00 | 63,050.40 | 0.00 |
| Steam | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Fuel | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Air | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Electricity, kwh/bomb | 0.00 | (1,738.00) | 0.00 | 0.00 | 0.00 |
| Activated Carbon | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| CO | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| N2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| H2O, vapor | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| H2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| CO2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| H | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| HO | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| NO | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Al | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| O | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| CH4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| NH3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| C2H4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| C3H6 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| C2H6 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| C2H2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| C3H8 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| CHN | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| C | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| | 3 | 6 | Burning Ground 7 | 8 | 9 | Solid Waste | Air Emissions | Resource Consumption |
|---|---|---|---|---|---|---|---|---|
| Flue Gas | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | |
| Total gaseous pollutant | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | |
| Al2O3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | |
| Ash | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | | |
| PBXN-109 | -509.25 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| TNAZ/Al | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Asphalt | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Bomb Case | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Potting | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Felt Pad | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Thermal Insulation | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| TCA (solvent) | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Water | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Steam | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Fuel | 0 ? | | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Air | 0 | 0.00 ? | | 0.00 | 0.00 | 0 | 0 | 0 |
| Electricity, kwh/bomb | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Activated Carbon | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| CO | 0 | 0.00 | 0.00 ? | | 0.00 | 0 ? | | 0 |
| N2 | 0 | 0.00 | 0.00 ? | | 0.00 | 0 ? | | 0 |
| H2O, vapor | 0 | 0.00 | 0.00 ? | | 0.00 | 0 ? | | 0 |
| H2 | 0 | 0.00 | 0.00 ? | | 0.00 | 0 ? | | 0 |
| CO2 | 0 | 0.00 | 0.00 ? | | 0.00 | 0 ? | | 0 |
| H | 0 | 0.00 | 0.00 ? | | 0.00 | 0 ? | | 0 |
| HO | 0 | 0.00 | 0.00 ? | | 0.00 | 0 ? | | 0 |
| NO | 0 | 0.00 | 0.00 ? | | 0.00 | 0 ? | | 0 |
| Al | 0 | 0.00 | 0.00 ? | | 0.00 | 0 ? | | 0 |
| O | 0 | 0.00 | 0.00 ? | | 0.00 | 0 ? | | 0 |
| CH4 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| NH3 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C2H4 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C3H6 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C2H6 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C2H2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| C3H8 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| CHN | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C | 0 | 0.00 | 0.00 | 0.00 | 52.38 | 52.38 | 0 | 0 |
| Flue Gas | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Total gaseous pollutant | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Al2O3 | 0 | 0.00 | 0.00 | 0.00 | 192.06 | 192.06 | 0 | 0 |
| Ash | 0 | 0.00 | 0.00 | 0.00 | 244.44 | 244.44 | 0 | 0 |

| | | Wastewater Treatment | | | | | Solid | Wastewater |
|---|---|---|---|---|---|---|---|---|
| | 4 | 10 | 11 | 12 | 16 | 22 | Waste | Emissions |
| PBXN-109 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |
| TNAZ/Al | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |
| Asphalt | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |
| Bomb Case | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |
| Potting | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |
| Felt Pad | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |
| Thermal Insulation | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |
| TCA (solvent) | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |
| Water | -63050.4 | 0.00 | 0.77 | 64,390.94 | -1296 | -45.3048 | 0.7681651 | 64390.937 |
| Steam | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |
| Fuel | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |
| Air | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |
| Electricity, kwh/bomb | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |
| Activated Carbon | 0 | (14.60) | 14.60 | 0.00 | 0 | 0 | 14.595138 | 0 |
| CO | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |
| N2 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |
| H2O, vapor | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |
| H2 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |
| CO2 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |
| H | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |
| HO | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |
| NO | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |
| Al | 0 | | 0.00 | 0.00 | 0 | 0 | 0 | 0 |
| O | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |
| CH4 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |
| NH3 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |
| C2H4 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| C3H6 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |
| C2H6 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |
| C2H2 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |
| C3H8 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |
| CHN | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |
| C | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |
| Flue Gas | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |
| Total gaseous pollutant | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |
| Al2O3 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |
| Ash | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 | 0 |

| | | | | Asphalt Liner Meltout | | | | | Wastewater |
|---|---|---|---|---|---|---|---|---|---|
| | 5 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | Emissions |
| PBXN-109 | -15.75 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 15.75 | 0.00 | 0 |
| TNAZ/Al | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Asphalt | -18.5 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 18.32 | 0.18 | 0 |
| Bomb Case | -1390 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1,390.00 | 0 |
| Potting | -3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Felt Pad | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Thermal Insulation | -25 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| TCA (solvent) | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Water | 0 | 0.00 | (1,296.00) | 0.00 | 1,296.00 | 714.00 | 0.00 | 0.00 | 714 |
| Steam | 0 | (714.00) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Fuel | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Air | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Electricity, kwh/bomb | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Activated Carbon | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| CO | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| N2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| H2O, vapor | 0 | 0.00 | 0.00 | 238.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| H2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| CO2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| H | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| HO | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| NO | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Al | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| O | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CH4 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| NH3 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| C2H4 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| C3H6 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| C2H6 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| C2H2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| C3H8 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| CHN | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| C | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Flue Gas | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Total gaseous pollutant | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Al2O3 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Ash | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |

| | Solidification | | | |
|---|---|---|---|---|
| | 18 | 20 | 21 | 22 |
| PBXN-109 | -15.75 | 0.00 | 15.75 | 0.00 |
| TNAZ/Al | 0 | 0.00 | 0.00 | 0.00 |
| Asphalt | -18.315 | 0.00 | 18.32 | 0.00 |
| Bomb Case | 0 | 0.00 | 0.00 | 0.00 |
| Potting | 0 | 0.00 | 0.00 | 0.00 |
| Felt Pad | 0 | 0.00 | 0.00 | 0.00 |
| Thermal Insulation | 0 | 0.00 | 0.00 | 0.00 |
| TCA (solvent) | 0 | 0.00 | 0.00 | 0.00 |
| Water | 0 | (46.00) | 0.70 | 45.30 |
| Steam | 0 | 0.00 | 0.00 | 0.00 |
| Fuel | 0 | 0.00 | 0.00 | 0.00 |
| Air | 0 | 0.00 | 0.00 | 0.00 |
| Electricity, kwh/bomb | 0 | 0.00 | 0.00 | 0.00 |
| Activated Carbon | 0 | 0.00 | 0.00 | 0.00 |
| CO | 0 | 0.00 | 0.00 | 0.00 |
| N2 | 0 | 0.00 | 0.00 | 0.00 |
| H2O, vapor | 0 | 0.00 | 0.00 | 0.00 |
| H2 | 0 | 0.00 | 0.00 | 0.00 |
| CO2 | 0 | 0.00 | 0.00 | 0.00 |
| H | 0 | 0.00 | 0.00 | 0.00 |
| HO | 0 | 0.00 | 0.00 | 0.00 |

| | | | | |
|---|---|---|---|---|
| NO | 0 | 0.00 | 0.00 | 0.00 |
| Al | 0 | 0.00 | 0.00 | 0.00 |
| O | 0 | 0.00 | 0.00 | 0.00 |
| CH4 | 0 | 0.00 | 0.00 | 0.00 |
| NH3 | 0 | 0.00 | 0.00 | 0.00 |
| C2H4 | 0 | 0.00 | 0.00 | 0.00 |
| C3H6 | 0 | 0.00 | 0.00 | 0.00 |
| C2H6 | 0 | 0.00 | 0.00 | 0.00 |
| C2H2 | 0 | 0.00 | 0.00 | 0.00 |
| C3H8 | 0 | 0.00 | 0.00 | 0.00 |
| CHN | 0 | 0.00 | 0.00 | 0.00 |
| C | 0 | 0.00 | 0.00 | 0.00 |
| Flue Gas | 0 | 0.00 | 0.00 | 0.00 |
| Total gaseous pollutant | 0 | 0.00 | 0.00 | 0.00 |
| Al2O3 | 0 | 0.00 | 0.00 | 0.00 |
| Ash | 0 | 0.00 | 0.00 | 0.00 |

| | | | Burning Grounds | | | Air | Solid |
|---|---|---|---|---|---|---|---|
| | 21 | 23 | 24 | 25 | 26 | Emissions | Waste |
| PBXN-109 | -15.75 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| TNAZ/Al | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Asphalt | -18.315 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Bomb Case | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Potting | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Felt Pad | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Thermal Insulation | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| TCA (solvent) | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Water | -0.695204082 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Steam | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Fuel | 0 ? | | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Air | 0 | 0.00 ? | | 0.00 | 0.00 | 0 | 0 |
| Electricity, kwh/bomb | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Activated Carbon | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| CO | 0 | 0.00 | 0.00 ? | | 0.00 ? | | 0 |
| N2 | 0 | 0.00 | 0.00 ? | | 0.00 ? | | 0 |
| H2O, vapor | 0 | 0.00 | 0.00 ? | | 0.00 ? | | 0 |
| H2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| CO2 | 0 | 0.00 | 0.00 ? | | 0.00 ? | | 0 |
| H | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| HO | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| NO | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Al | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| O | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| CH4 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| NH3 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C2H4 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C3H6 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C2H6 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C2H2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C3H8 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| CHN | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Flue Gas | 0 | 0.00 | 0.00 ? | | 0.00 ? | | 0 |
| Total gaseous pollutant | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Al2O3 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Ash | 0 ? | | 0.00 | 0.00 | 0.00 | 0 | 0 |

| | 19 | 27 | Flashing 28 | 29 | 30 | 31 | Solid Waste | Recycle |
|---|---|---|---|---|---|---|---|---|
| PBXN-109 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| TNAZ/Al | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Asphalt | -0.185 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Bomb Case | -1390 | 0.00 | 0.00 | 0.00 | 0.00 | 1,390.00 | 0 | 1390 |
| Potting | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Felt Pad | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Thermal Insulation | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| TCA (solvent) | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Water | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Steam | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Fuel | 0 ? | | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Air | 0 | 0.00 ? | | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Electricity, kwh/bomb | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Activated Carbon | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| CO | 0 | 0.00 | 0.00 ? | | 0.00 | 0.00 | 0 | 0 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| N2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| H2O, vapor | 0 | 0.00 | 0.00 ? | | 0.00 | 0.00 | 0 | 0 |
| H2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| CO2 | 0 | 0.00 | 0.00 ? | | 0.00 | 0.00 | 0 | 0 |
| H | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| HO | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| NO | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Al | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| O | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| CH4 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| NH3 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C2H4 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C3H6 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C2H6 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C2H2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C3H8 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| CHN | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Flue Gas | 0 | 0.00 | 0.00 ? | | 0.00 | 0.00 | 0 | 0 |
| Total gaseous pollutant | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Al2O3 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Ash | 0 | 0.00 | 0.00 | 0.00 ? | | 0.00 ? | | 0 |

TABLE 3. INVENTORY FOR OPTION 2 TNAZ DEMILITARIZATION PROCESS
(All units in lb/bomb, except electricity in kwh/bomb)

| | | | HE Removal | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| PBXN-109 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| TNAZ/Al | (525.00) | 0.00 | 509.25 | 0.00 | 15.75 |
| Asphalt | (18.50) | 0.00 | 0.00 | 0.00 | 18.50 |
| Bomb Case | (1,390.00) | 0.00 | 0.00 | 0.00 | 1,390.00 |
| Potting | (3.00) | 0.00 | 0.00 | 0.00 | 3.00 |
| Felt Pad | ? | 0.00 | 0.00 | 0.00 | ? |
| Thermal Insulation | (25.00) | 0.00 | 0.00 | 0.00 | 25.00 |
| TCA (solvent) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Water | 0.00 | (63,050.40) | 0.00 | 63,050.40 | 0.00 |
| Steam | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Fuel | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Air | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Electricity, kwh/bomb | 0.00 | (1,738.00) | 0.00 | 0.00 | 0.00 |
| Activated Carbon | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| CO | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| N2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| H2O | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| H2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| CO2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| H | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| HO | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| NO | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Al | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| O | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| CH4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| NH3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| C2H4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| C3H6 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| C2H6 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| C2H2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| C3H8 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| CHN | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| C | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| | | | | | |
|---|---|---|---|---|---|
| Flue Gas | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total gaseous pollutant | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Al2O3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Ash | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| | 3 | 6 | Burning Ground 7 | 8 | 9 | Air Emissions | Solid Waste |
|---|---|---|---|---|---|---|---|
| PBXN-109 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| TNAZ/Al | -509.25 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Asphalt | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Bomb Case | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Potting | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Felt Pad | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Thermal Insulation | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| TCA (solvent) | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Water | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Steam | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Fuel | 0 ? | | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Air | 0 | 0.00 ? | | 0.00 | 0.00 | 0 | 0 |
| Electricity, kwh/bomb | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Activated Carbon | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| CO | 0 | 0.00 | 0.00 | (174.16) | 0.00 | -174.1635 | 0 |
| N2 | 0 | 0.00 | 0.00 | (118.81) | 0.00 | -118.8056 | 0 |
| H2O | 0 | 0.00 | 0.00 | (9.62) | 0.00 | -9.6224 | 0 |
| H2 | 0 | 0.00 | 0.00 | (6.93) | 0.00 | -6.9258 | 0 |
| CO2 | 0 | 0.00 | 0.00 | (6.31) | 0.00 | -6.3147 | 0 |
| H | 0 | 0.00 | 0.00 | (0.50) | 0.00 | -0.5044 | 0 |
| HO | 0 | 0.00 | 0.00 | (0.35) | 0.00 | -0.3492 | 0 |
| NO | 0 | 0.00 | 0.00 | (0.05) | 0.00 | -0.0485 | 0 |
| Al | 0 | 0.00 | 0.00 | (0.05) | 0.00 | -0.0485 | 0 |
| O | 0 | 0.00 | 0.00 | (0.05) | 0.00 | -0.0485 | 0 |
| CH4 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| NH3 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C2H4 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C3H6 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C2H6 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C2H2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C3H8 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| CHN | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C | 0 | 0.00 | 0.00 | 0.00 | 52.38 | 0 | 52.38 |
| Flue Gas | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Total gaseous pollutant | 0 | 0.00 | 0.00 | (175.11) | 0.00 | -175.1141 | 0 |
| Al2O3 | 0 | 0.00 | 0.00 | 0.00 | (192.29) | 0 | -192.2928 |
| Ash | 0 | 0.00 | 0.00 | 0.00 | (139.91) | 0 | -139.9128 |

| | | Wastewater Treament | | | | | Solid | Wastewater |
|---|---|---|---|---|---|---|---|---|
| | 4 | 10 | 11 | 12 | 16 | 21 | Waste | Emissions |
| PBXN-109 | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 |
| TNAZ/Al | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 |
| Asphalt | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 |
| Bomb Case | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 |
| Potting | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 |
| Felt Pad | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 |
| Thermal Insulation | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 |
| TCA (solvent) | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 |
| Water | -63050.4 | 0.00 | 0.74 | 61,706.97 | 1296 | | 0.7361462 | 61706.969 |
| Steam | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 |
| Fuel | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 |
| Air | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 |
| Electricity, kwh/bomb | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 |
| Activated Carbon | 0 | 13.99 | 13.99 | 0.00 | 0 | | 13.986778 | 0 |
| CO | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 |
| N2 | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 |
| H2O | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 |
| H2 | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 |
| CO2 | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 |
| H | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 |
| HO | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 |
| NO | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 |
| Al | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 |
| O | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 |
| CH4 | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 |
| NH3 | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 |
| C2H4 | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 |
| C3H6 | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 |

| | 5 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | Air Emissions | Wastewater Emissions |
|---|---|---|---|---|---|---|---|---|---|---|
| C2H6 | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 | | |
| C2H2 | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 | | |
| C3H8 | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 | | |
| CHN | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 | | |
| C | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 | | |
| Flue Gas | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 | | |
| Total gaseous pollutant | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 | | |
| Al2O3 | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 | | |
| Ash | 0 | 0.00 | 0.00 | 0.00 | 0 | | 0 | 0 | | |

| | | | Asphalt Liner Meltout | | | | | | Air | Wastewater |
|---|---|---|---|---|---|---|---|---|---|---|
| | 5 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | Emissions | Emissions |
| PBXN-109 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0 |
| TNAZ/Al | -15.75 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 15.75 | 0.00 | 0 | 0 |
| Asphalt | -18.5 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 18.32 | 0.18 | 0 | 0 |
| Bomb Case | -1390 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 1,390.00 | 0 | 0 |
| Potting | -3 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 3.00 | 0 | 0 |
| Felt Pad | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0.00 ? | | 0 | 0 |
| Thermal Insulation | -25 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 25.00 | 0 | 0 |
| TCA (solvent) | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0 |
| Water | 0 | 0.00 | (1,296.00) | 0.00 | (1,296.00) | -714 | 0.00 | 0.00 | 0 | -714 |
| Steam | 0 | (714.00) | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0 |
| Fuel | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0 |
| Air | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0 |
| Electricity, kwh/bomb | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0 |
| Activated Carbon | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0 |
| CO | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0 |
| N2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0 |
| H2O | 0 | 0.00 | 0.00 | 238.00 | 0.00 | 0 | 0.00 | 0.00 | 238 | 0 |
| H2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0 |
| CO2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0 |
| H | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0 |
| HO | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0 |
| NO | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0 |
| Al | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0 |
| O | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| CH4 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0 |
| NH3 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0 |
| C2H4 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0 |
| C3H6 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0 |
| C2H6 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0 |
| C2H2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0 |
| C3H8 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0 |
| CHN | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0 |
| C | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0 |
| Flue Gas | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0 |
| Total gaseous pollutant | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0 |
| Al2O3 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0 |
| Ash | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0 |

| | | Solidification | | |
|---|---|---|---|---|
| | 18 | 20 | 21 | 22 |
| PBXN-109 | 0 | 0.00 | 0.00 | 0.00 |
| TNAZ/Al | -15.75 | 0.00 | 15.75 | 0.00 |
| Asphalt | -18.315 | 0.00 | 18.32 | 0.00 |
| Bomb Case | 0 | 0.00 | 0.00 | 0.00 |
| Potting | 0 | 0.00 | 0.00 | 0.00 |
| Felt Pad | 0 | 0.00 | 0.00 | 0.00 |
| Thermal Insulation | 0 | 0.00 | 0.00 | 0.00 |
| TCA (solvent) | 0 | 0.00 | 0.00 | 0.00 |
| Water | 0 | (46.00) | 0.70 | (46.70) |
| Steam | 0 | 0.00 | 0.00 | 0.00 |
| Fuel | 0 | 0.00 | 0.00 | 0.00 |
| Air | 0 | 0.00 | 0.00 | 0.00 |
| Electricity, kwh/bomb | 0 | 0.00 | 0.00 | 0.00 |
| Activated Carbon | 0 | 0.00 | 0.00 | 0.00 |
| CO | 0 | 0.00 | 0.00 | 0.00 |
| N2 | 0 | 0.00 | 0.00 | 0.00 |
| H2O | 0 | 0.00 | 0.00 | 0.00 |
| H2 | 0 | 0.00 | 0.00 | 0.00 |
| CO2 | 0 | 0.00 | 0.00 | 0.00 |

| | | | | |
|---|---|---|---|---|
| H | 0 | 0.00 | 0.00 | 0.00 |
| HO | 0 | 0.00 | 0.00 | 0.00 |
| NO | 0 | 0.00 | 0.00 | 0.00 |
| Al | 0 | 0.00 | 0.00 | 0.00 |
| O | 0 | 0.00 | 0.00 | 0.00 |
| CH4 | 0 | 0.00 | 0.00 | 0.00 |
| NH3 | 0 | 0.00 | 0.00 | 0.00 |
| C2H4 | 0 | 0.00 | 0.00 | 0.00 |
| C3H6 | 0 | 0.00 | 0.00 | 0.00 |
| C2H6 | 0 | 0.00 | 0.00 | 0.00 |
| C2H2 | 0 | 0.00 | 0.00 | 0.00 |
| C3H8 | 0 | 0.00 | 0.00 | 0.00 |
| CHN | 0 | 0.00 | 0.00 | 0.00 |
| C | 0 | 0.00 | 0.00 | 0.00 |
| Flue Gas | 0 | 0.00 | 0.00 | 0.00 |
| Total gaseous pollutant | 0 | 0.00 | 0.00 | 0.00 |
| Al2O3 | 0 | 0.00 | 0.00 | 0.00 |
| Ash | 0 | 0.00 | 0.00 | 0.00 |

| | | | Burning Ground | | | Solid | Air |
|---|---|---|---|---|---|---|---|
| | 21 | 23 | 24 | 25 | 27 | Waste | Emissions |
| PBXN-109 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| TNAZ/Al | -15.75 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Asphalt | -18.315 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Bomb Case | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Potting | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Felt Pad | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Thermal Insulation | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| TCA (solvent) | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Water | -0.695204082 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Steam | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Fuel | 0 ? | | 0.00 | 0.00 ? | | 0 ? | |
| Air | 0 | 0.00 ? | | 0.00 | 0.00 | 0 | 0 |
| Electricity, kwh/bomb | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Activated Carbon | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| CO | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| N2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| H2O | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| H2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| CO2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| H | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| HO | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| NO | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Al | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| O | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| CH4 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| NH3 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C2H4 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C3H6 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C2H6 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C2H2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C3H8 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| CHN | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Flue Gas | 0 | 0.00 | 0.00 ? | | 0.00 ? | | 0 |
| Total gaseous pollutant | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Al2O3 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Ash | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |

| | 19 | 26 | Flashing 28 | 29 | 30 | 31 | Air Emissions | Solid Waste | Recycle |
|---|---|---|---|---|---|---|---|---|---|
| PBXN-109 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| TNAZ/Al | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Asphalt | -0.185 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Bomb Case | -1390 | 0.00 | 0.00 | 0.00 | 0.00 | 1,390.00 | 0 | 0 | 0 |
| Potting | -3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Felt Pad | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Thermal Insulation | -25 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| TCA (solvent) | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Water | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Steam | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Fuel | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Air | 0 | 0.00 ? | | 0.00 | 0.00 | 0.00 ? | | 0 | 0 |
| Electricity, kwh/bomb | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Activated Carbon | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| CO | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| N2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| H2O | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| H2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| CO2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| H | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| HO | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| NO | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Al | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| O | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| CH4 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| NH3 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C2H4 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C3H6 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C2H6 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C2H2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C3H8 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| CHN | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Flue Gas | 0 | 0.00 | 0.00 ? | | 0.00 | 0.00 | 0 ? | | 0 |
| Total gaseous pollutant | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Al2O3 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Ash | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |

TABLE 4. INVENTORY FOR OPTION 3 TNAZ DEMILITARIZATION PROCESS
(All units in lb/bomb, except electricity in kwh/bomb)

| | 1 | 2 | 3 | 4 | 4A | 5 | 6 | 7 | Air Emissions | wastewater Emissions |
|---|---|---|---|---|---|---|---|---|---|---|
| PBXN-109 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| TNAZ/Al | (525.00) | 0.00 | 0.00 | 525.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Asphalt | (18.50) | 0.00 | 0.00 | 18.32 | 0.00 | 0.00 | 0.00 | 0.18 | 0 | 0 |
| Bomb Case | (1,390.00) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1,390.00 | 0 | 0 |
| Potting | (3.00) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.00 | 0 | 0 |
| Felt Pad | ? | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Thermal Insulation | (25.00) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 25.00 | 0 | 0 |
| TCA (solvent) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Water | 0.00 | 0.00 | (1,296.00) | 0.00 | 0.00 | 1,296.00 | 0.00 | 0.00 | 0 | 0 |
| Steam | 0.00 | (981.00) | 0.00 | 0.00 | 327.00 | 0.00 | 654.00 | 0.00 | 327 | 654 |
| Fuel | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Air | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Electricity, kwh/bomb | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Activated Carbon | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| CO | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| N2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| H2O | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| H2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| CO2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| H | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| HO | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| NO | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Al | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| O | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| CH4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| NH3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C2H4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C3H6 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C2H6 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C2H2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C3H8 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| CHN | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Flue Gas | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Total gaseous pollutant | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Al2O3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Ash | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |

| | | Solidification | | |
|---|---|---|---|---|
| | 4 | 8 | 9 | 10 |
| PBXN-109 | 0 | 0.00 | 0.00 | 0.00 |
| TNAZ/Al | -525 | 0.00 | 525.00 | 0.00 |
| Asphalt | -18.315 | 0.00 | 18.32 | 0.00 |
| Bomb Case | 0 | 0.00 | 0.00 | 0.00 |
| Potting | 0 | 0.00 | 0.00 | 0.00 |
| Felt Pad | 0 | 0.00 | 0.00 | 0.00 |
| Thermal Insulation | 0 | 0.00 | 0.00 | 0.00 |
| TCA (solvent) | 0 | 0.00 | 0.00 | 0.00 |
| Water | 0 | (2,284.00) | 11.09 | (2,295.09) |
| Steam | 0 | 0.00 | 0.00 | 0.00 |
| Fuel | 0 | 0.00 | 0.00 | 0.00 |
| Air | 0 | 0.00 | 0.00 | 0.00 |
| Electricity, kwh/bomb | 0 | 0.00 | 0.00 | 0.00 |
| Activated Carbon | 0 | 0.00 | 0.00 | 0.00 |
| CO | 0 | 0.00 | 0.00 | 0.00 |
| N2 | 0 | 0.00 | 0.00 | 0.00 |
| H2O | 0 | 0.00 | 0.00 | 0.00 |
| H2 | 0 | 0.00 | 0.00 | 0.00 |
| CO2 | 0 | 0.00 | 0.00 | 0.00 |
| H | 0 | 0.00 | 0.00 | 0.00 |
| HO | 0 | 0.00 | 0.00 | 0.00 |
| NO | 0 | 0.00 | 0.00 | 0.00 |
| Al | 0 | 0.00 | 0.00 | 0.00 |
| O | 0 | 0.00 | 0.00 | 0.00 |
| CH4 | 0 | 0.00 | 0.00 | 0.00 |
| NH3 | 0 | 0.00 | 0.00 | 0.00 |
| C2H4 | 0 | 0.00 | 0.00 | 0.00 |
| C3H6 | 0 | 0.00 | 0.00 | 0.00 |
| C2H6 | 0 | 0.00 | 0.00 | 0.00 |

| | | | | |
|---|---|---|---|---|
| C2H2 | 0 | 0.00 | 0.00 | 0.00 |
| C3H8 | 0 | 0.00 | 0.00 | 0.00 |
| CHN | 0 | 0.00 | 0.00 | 0.00 |
| C | 0 | 0.00 | 0.00 | 0.00 |
| Flue Gas | 0 | 0.00 | 0.00 | 0.00 |
| Total gaseous pollutant | 0 | 0.00 | 0.00 | 0.00 |
| Al2O3 | 0 | 0.00 | 0.00 | 0.00 |
| Ash | 0 | 0.00 | 0.00 | 0.00 |

| | | | Wastewater Treament | | | Solid | Wastewater |
|---|---|---|---|---|---|---|---|
| | 5 | 10 | 11 | 12 | 13 | Waste | Emissions |
| PBXN-109 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| TNAZ/Al | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Asphalt | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Bomb Case | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Potting | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Felt Pad | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Thermal Insulation | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| TCA (solvent) | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Water | -1296 | 2295.08806 | 0.00 | (0.03) | (999.06) | -0.027379407 | -999.06068 |
| Steam | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Fuel | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Air | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Electricity, kwh/bomb | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Activated Carbon | 0 | 0 | (0.52) | (0.52) | 0.00 | -0.520208724 | 0 |
| CO | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| N2 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| H2O | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| H2 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| CO2 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| H | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| HO | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| NO | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Al | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| O | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| CH4 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| NH3 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C2H4 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C3H6 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C2H6 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C2H2 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C3H8 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| CHN | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Flue Gas | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Total gaseous pollutant | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Al2O3 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Ash | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |

| | | | | Flashing | | | Air | Solid | |
|---|---|---|---|---|---|---|---|---|---|
| | 7 | 14 | 15 | 16 | 17 | 18 | Emissions | Wastes | Recycle |
| PBXN-109 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| TNAZ/Al | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Asphalt | -0.185 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Bomb Case | -1390 | 0.00 | 0.00 | 0.00 | 0.00 | 1,390.00 | 0 | 0 | 1390 |
| Potting | -3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Felt Pad | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Thermal Insulation | -25 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| TCA (solvent) | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Water | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Steam | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Fuel | 0 ? | | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Air | 0 | 0.00 ? | | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Electricity, kwh/bomb | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Activated Carbon | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| CO | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| N2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| H2O | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| H2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| CO2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| H | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| HO | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| NO | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Al | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| O | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| CH4 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| NH3 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C2H4 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C3H6 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C2H6 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C2H2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C3H8 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| CHN | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| C | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Flue Gas | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Total gaseous pollutant | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Al2O3 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |
| Ash | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 | 0 |

| | | | | Burning Ground | | Air | Solid |
|---|---|---|---|---|---|---|---|
| | 9 | 19 | 20 | 21 | 22 | Emissions | Waste |
| PBXN-109 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| TNAZ/Al | -525 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Asphalt | -18.315 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Bomb Case | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Potting | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Felt Pad | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Thermal Insulation | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| TCA (solvent) | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Water | -11.0880612 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Steam | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Fuel | 0 ? | | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Air | 0 | 0.00 ? | | 0.00 | 0.00 | 0 | 0 |
| Electricity, kwh/bomb | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Activated Carbon | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| CO | 0 | 0.00 | 0.00 | 179.55 | 0.00 | 179.55 | 0 |
| N2 | 0 | 0.00 | 0.00 | 122.48 | 0.00 | 122.48 | 0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| H2O | 0 | 0.00 | 0.00 | 9.92 | 0.00 | 9.92 | 0 |
| H2 | 0 | 0.00 | 0.00 | 7.14 | 0.00 | 7.14 | 0 |
| CO2 | 0 | 0.00 | 0.00 | 6.51 | 0.00 | 6.51 | 0 |
| H | 0 | 0.00 | 0.00 | 0.52 | 0.00 | 0.52 | 0 |
| HO | 0 | 0.00 | 0.00 | 0.36 | 0.00 | 0.36 | 0 |
| NO | 0 | 0.00 | 0.00 | 0.05 | 0.00 | 0.05 | 0 |
| Al | 0 | 0.00 | 0.00 | 0.05 | 0.00 | 0.05 | 0 |
| O | 0 | 0.00 | 0.00 | 0.05 | 0.00 | 0.05 | 0 |
| CH4 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| NH3 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C2H4 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C3H6 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C2H6 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C2H2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C3H8 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| CHN | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Flue Gas | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Total gaseous pollutant | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Al2O3 | 0 | 0.00 | 0.00 | 0.00 | 198.24 | 0 | 198.24 |
| Ash | 0 | 0.00 | 0.00 | 0.00 | 198.24 | 0 | 198.24 |

| | | | HE/Asphalt Melting | | | Wastewater |
|---|---|---|---|---|---|---|
| | 9 | 23 | 24 | 25 | 26 | Emissions |
| PBXN-109 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| TNAZ/Al | -525 | 0.00 | 0.00 | 0.19 | 524.82 | 0 |
| Asphalt | -18.315 | 0.00 | 0.00 | 18.32 | 0.00 | 0 |
| Bomb Case | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Potting | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Felt Pad | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Thermal Insulation | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| TCA (solvent) | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Water | -11.0880612 | 0.00 | 162.00 | 0.00 | 0.00 | 162 |
| Steam | 0 | (162.00) | 0.00 | 0.00 | 0.00 | 0 |
| Fuel | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Air | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Electricity, kwh/bomb | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Activated Carbon | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| CO | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| N2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| H2O | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| H2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| CO2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| H | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| HO | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| NO | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Al | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| O | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| CH4 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| NH3 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| C2H4 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| C3H6 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| C2H6 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| C2H2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| C3H8 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| CHN | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| C | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Flue Gas | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Total gaseous pollutant | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Al2O3 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |
| Ash | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 |

| | | | Solidification | | |
|---|---|---|---|---|---|
| | 26 | 27 | 28 | 29 | Recycle |
| PBXN-109 | 0 | 0.00 | 0.00 | 0.00 | 0 |
| TNAZ/Al | -524.815 | 0.00 | 0.19 | 0.00 | 0.185 |
| Asphalt | 0 | 0.00 | 18.32 | 0.00 | 18.315 |
| Bomb Case | 0 | 0.00 | 0.00 | 0.00 | 0 |
| Potting | 0 | 0.00 | 0.00 | 0.00 | 0 |
| Felt Pad | 0 | 0.00 | 0.00 | 0.00 | 0 |
| Thermal Insulation | 0 | 0.00 | 0.00 | 0.00 | 0 |
| TCA (solvent) | 0 | 0.00 | 0.00 | 0.00 | 0 |
| Water | 0 | 1,155.00 | 0.38 | 1,154.62 | 0.37755102 |

| | | | | | |
|---|---|---|---|---|---|
| Steam | 0 | 0.00 | 0.00 | 0.00 | 0 |
| Fuel | 0 | 0.00 | 0.00 | 0.00 | 0 |
| Air | 0 | 0.00 | 0.00 | 0.00 | 0 |
| Electricity, kwh/bomb | 0 | 0.00 | 0.00 | 0.00 | 0 |
| Activated Carbon | 0 | 0.00 | 0.00 | 0.00 | 0 |
| CO | 0 | 0.00 | 0.00 | 0.00 | 0 |
| N2 | 0 | 0.00 | 0.00 | 0.00 | 0 |
| H2O | 0 | 0.00 | 0.00 | 0.00 | 0 |
| H2 | 0 | 0.00 | 0.00 | 0.00 | 0 |
| CO2 | 0 | 0.00 | 0.00 | 0.00 | 0 |
| H | 0 | 0.00 | 0.00 | 0.00 | 0 |
| HO | 0 | 0.00 | 0.00 | 0.00 | 0 |
| NO | 0 | 0.00 | 0.00 | 0.00 | 0 |
| Al | 0 | 0.00 | 0.00 | 0.00 | 0 |
| O | 0 | 0.00 | 0.00 | 0.00 | 0 |
| CH4 | 0 | 0.00 | 0.00 | 0.00 | 0 |
| NH3 | 0 | 0.00 | 0.00 | 0.00 | 0 |
| C2H4 | 0 | 0.00 | 0.00 | 0.00 | 0 |
| C3H6 | 0 | 0.00 | 0.00 | 0.00 | 0 |
| C2H6 | 0 | 0.00 | 0.00 | 0.00 | 0 |
| C2H2 | 0 | 0.00 | 0.00 | 0.00 | 0 |
| C3H8 | 0 | 0.00 | 0.00 | 0.00 | 0 |
| CHN | 0 | 0.00 | 0.00 | 0.00 | 0 |
| C | 0 | 0.00 | 0.00 | 0.00 | 0 |
| Flue Gas | 0 | 0.00 | 0.00 | 0.00 | 0 |
| Total gaseous pollutant | 0 | 0.00 | 0.00 | 0.00 | 0 |
| Al2O3 | 0 | 0.00 | 0.00 | 0.00 | 0 |
| Ash | 0 | 0.00 | 0.00 | 0.00 | 0 |

| | Wastewater Treatment | | | | Solid | Wastewater |
|---|---|---|---|---|---|---|
| | 29 | 30 | 31 | 32 | Waste | Emissions |
| PBXN-109 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| TNAZ/Al | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Asphalt | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Bomb Case | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Potting | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Felt Pad | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Thermal Insulation | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| TCA (solvent) | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Water | -1154.62245 | 0.00 | (0.01) | 1,154.64 | -0.01377415 | 1154.636223 |
| Steam | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Fuel | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Air | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Electricity, kwh/bomb | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Activated Carbon | 0 | (0.26) | 0.26 | 0.00 | 0.261708769 | 0 |
| CO | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| N2 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| H2O | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| H2 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| CO2 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| H | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| HO | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| NO | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Al | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| O | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| CH4 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| NH3 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C2H4 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C3H6 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C2H6 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C2H2 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C3H8 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| CHN | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Flue Gas | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Total gaseous pollutant | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Al2O3 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Ash | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |

| | Solidification | | | |
|---|---|---|---|---|
| | 25 | 33 | 34 | 35 |
| PBXN-109 | 0 | 0.00 | 0.00 | 0.00 |
| TNAZ/Al | -0.185 | 0.00 | 0.19 | 0.00 |

| | | | | |
|---|---|---|---|---|
| Asphalt | -18.315 | 0.00 | 18.32 | 0.00 |
| Bomb Case | 0 | 0.00 | 0.00 | 0.00 |
| Potting | 0 | 0.00 | 0.00 | 0.00 |
| Felt Pad | 0 | 0.00 | 0.00 | 0.00 |
| Thermal Insulation | 0 | 0.00 | 0.00 | 0.00 |
| TCA (solvent) | 0 | 0.00 | 0.00 | 0.00 |
| Water | 0 | (39.00) | 0.19 | 38.81 |
| Steam | 0 | 0.00 | 0.00 | 0.00 |
| Fuel | 0 | 0.00 | 0.00 | 0.00 |
| Air | 0 | 0.00 | 0.00 | 0.00 |
| Electricity, kwh/bomb | 0 | 0.00 | 0.00 | 0.00 |
| Activated Carbon | 0 | 0.00 | 0.00 | 0.00 |
| CO | 0 | 0.00 | 0.00 | 0.00 |
| N2 | 0 | 0.00 | 0.00 | 0.00 |
| H2O | 0 | 0.00 | 0.00 | 0.00 |
| H2 | 0 | 0.00 | 0.00 | 0.00 |
| CO2 | 0 | 0.00 | 0.00 | 0.00 |
| H | 0 | 0.00 | 0.00 | 0.00 |
| HO | 0 | 0.00 | 0.00 | 0.00 |
| NO | 0 | 0.00 | 0.00 | 0.00 |
| Al | 0 | 0.00 | 0.00 | 0.00 |
| O | 0 | 0.00 | 0.00 | 0.00 |
| CH4 | 0 | 0.00 | 0.00 | 0.00 |
| NH3 | 0 | 0.00 | 0.00 | 0.00 |
| C2H4 | 0 | 0.00 | 0.00 | 0.00 |
| C3H6 | 0 | 0.00 | 0.00 | 0.00 |
| C2H6 | 0 | 0.00 | 0.00 | 0.00 |
| C2H2 | 0 | 0.00 | 0.00 | 0.00 |
| C3H8 | 0 | 0.00 | 0.00 | 0.00 |
| CHN | 0 | 0.00 | 0.00 | 0.00 |
| C | 0 | 0.00 | 0.00 | 0.00 |
| Flue Gas | 0 | 0.00 | 0.00 | 0.00 |
| Total gaseous pollutant | 0 | 0.00 | 0.00 | 0.00 |
| Al2O3 | 0 | 0.00 | 0.00 | 0.00 |
| Ash | 0 | 0.00 | 0.00 | 0.00 |

Solid Wastewater

| | 35 | 36 | 37 | 38 | Waste | Emissions |
|---|---|---|---|---|---|---|
| PBXN-109 | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| TNAZ/Al | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Asphalt | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Bomb Case | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Potting | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Felt Pad | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Thermal Insulation | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| TCA (solvent) | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Water | -38.8131313 | 0.00 | 38.81 | 0.00 | 38.81313131 | 0 |
| Steam | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Fuel | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Air | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Electricity, kwh/bomb | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Activated Carbon | 0 | (0.01) | 0.01 | 0.00 | 0.008797453 | 0 |
| CO | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| $N_2$ | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| $H_2O$ | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| $H_2$ | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| $CO_2$ | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| H | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| HO | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| NO | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Al | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| O | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| $CH_4$ | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| $NH_3$ | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| $C_2H_4$ | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| $C_3H_6$ | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| $C_2H_6$ | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| $C_2H_2$ | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| $C_3H_8$ | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| CHN | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Flue Gas | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Total gaseous pollutant | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| $Al_2O_3$ | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Ash | 0 | 0.00 | 0.00 | 0.00 | 0 | 0 |

| | 34 | 39 | 40 | 41 | 42 | Air Emissions | Solid Waste |
|---|---|---|---|---|---|---|---|
| PBXN-109 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| TNAZ/Al | -0.185 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Asphalt | -18.315 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Bomb Case | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Potting | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Felt Pad | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Thermal Insulation | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| TCA (solvent) | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Water | -0.18686869 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Steam | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Fuel | 0 ? | | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Air | 0 | 0.00 ? | | 0.00 | 0.00 | 0 | 0 |
| Electricity, kwh/bomb | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Activated Carbon | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| CO | 0 | 0.00 | 0.00 | 0.06 | 0.00 | 0.06327 | 0 |
| N2 | 0 | 0.00 | 0.00 | 0.04 | 0.00 | 0.043159619 | 0 |
| H2O | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.003495619 | 0 |
| H2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.002516 | 0 |
| CO2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.002294 | 0 |
| H | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.000183238 | 0 |
| HO | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.000126857 | 0 |
| NO | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 1.7619E-05 | 0 |
| Al | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 1.7619E-05 | 0 |
| O | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 1.7619E-05 | 0 |
| CH4 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| NH3 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C2H4 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C3H6 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C2H6 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C2H2 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| C3H8 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| CHN | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| C | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Flue Gas | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Total gaseous pollutant | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0 |
| Al2O3 | 0 | 0.00 | 0.00 | 0.00 | 0.07 | 0 | 0.069856 |
| Ash | 0 | 0.00 | 0.00 | 0.00 | 0.07 | 0 | 0.069856 |

Natural gas

| | Mwt | heat value | Rio Arriba, | Terrell, Tex | Stanton, Ka | San Juan, N | Olds Field, | Cliffside, Texas | | |
|---|---|---|---|---|---|---|---|---|---|---|
| mol% | | MJ/M^3 | | | | | | | | |
| Methane | 16.043 | 37.57 | 96.91 | 45.64 | 67.56 | 77.28 | 52.34 | 65.8 | | |
| ethane | 30.07 | 65.83 | 1.33 | 0.21 | 6.23 | 11.18 | 0.41 | 3.8 | | |
| propane | 44.097 | 93.6 | 0.19 | | 3.18 | 5.83 | 0.14 | 1.7 | | |
| butane | 58.123 | 120.98 | 0.05 | | 1.42 | 2.34 | 0.16 | 0.8 | | |
| pentane+ | 72.15 | 148.84 | 0.02 | | 0.04 | 1.18 | 0.41 | 0.5 | | |
| CO2 | 44.01 | 0 | 0.82 | 53.93 | 0.07 | 0.8 | 8.22 | | | |
| H2S | 34.076 | 23.7 | | 0.01 | | | 35.79 | | | |
| N2 | 28.013 | 0 | 0.68 | 0.21 | 21.14 | 1.39 | 2.53 | 25.6 | avg | SD (rel) |
| Mol wt: | | | 16.62585 | 31.182 | 20.92126 | 21.28362 | 25.49289 | 20.44567 | 19.61024 | 10.79% |
| heating valu | MJ/M^3 | | 37.6 | 17.3 | 34.9 | 46.8 | 30 | 30.7 | 39.76667 | 12.81% |
| | MJ/KG | | 50.65847 | 12.42768 | 37.36678 | 49.25478 | 26.36029 | 33.63451 | 45.76001 | 13.03% |
| | 0.0224M^3/mol | | | too high CO2 content for use | | | too high Sulfur content | too low heating value(?) | | |

Source: Kirk Othmer Ed 4 vol 12 1993

MJ/m^3

Heating values for processed city natural gas:
source Perry 6 (1984)
averaged from table 9-14

Btu/scf 1049.571

Synopsis of table 9-14

| | Mwt | heat value | Baltimore | Columbus | Houston | Burmingham | Washington | Phoenix | | |
|---|---|---|---|---|---|---|---|---|---|---|
| mol% | | MJ/M^3 | Md | Ohio | Tx | Al | DC | Az | | |
| Methane | 16.043 | 37.57 | 94.4 | 93.14 | 92.5 | 93.14 | 95.15 | 87.37 | | |
| ethane | 30.07 | 65.83 | 3.4 | 3.58 | 4.8 | 2.5 | 2.84 | 8.11 | | |
| propane | 44.097 | 93.6 | 0.6 | 0.66 | 2 | 0.67 | 0.63 | 2.26 | | |
| butane | 58.123 | 120.98 | 0.5 | 0.22 | 0.3 | 0.32 | 0.24 | 0.13 | | |
| pentane+ | 72.15 | 148.84 | 0 | 0.09 | 0 | 0.12 | 0.05 | 0 | | |
| CO2 | 44.01 | 0 | 0.6 | 0.85 | 0.27 | 1.06 | 0.62 | 0.61 | | |
| H2S | 34.076 | 23.7 | | 0.01 | | | | | | |
| N2 | 28.013 | 0 | 0.5 | 0.21 | 21.14 | 2.14 | 0.42 | 1.37 | avg | SD (rel) |
| Mol wt: | | | 17.12629 | 16.93912 | 23.38022 | 17.32821 | 16.9628 | 18.17984 | 18.31941 | 15.84% |
| heating valu | MJ/M^3 | | 39.2023 | 38.3444 | 38.4563 | 38.1952 | 38.8666 | 39.9483 | 38.83552 | 1.10% |
| | MJ/KG | | 51.27388 | 50.70597 | 36.84401 | 49.37455 | 51.32477 | 49.22167 | 48.12414 | 13.30% |

0.0224M^3/mol

lanufactured gas

ata from KO 2 (1964) for "modern mechanical method"

| | Moisture | Heating valueBtu/lb | | Gas yield scf/ton | | gas lb/lb co | Gross heat value Btu/s | | Btu/ton coa | Btu/lb coal | Tar yield gal/ton | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | wet | dry | wet base | dry base | | wet base | dry base | wet base | wet base | wet base | dry base |
| nthracite | 0.051 | 10800 | 11380.4 | 123900 | 130558.5 | | 138 | 145.4162 | 17098200 | 8549.1 | 9.5 | 10.01054 |
| elgian Co | 0.026 | 11980 | 12299.79 | 120900 | 124127.3 | | 150 | 154.0041 | 18135000 | 9067.5 | 1 | 1.026694 |
| addesley | 0.05 | 12080 | 12715.79 | 116100 | 122210.5 | 3.581182 | 165.6 | 174.3158 | 19226160 | 9613.08 | 21 | 22.10526 |

(Column groups: Gas; gas heat value; Tar data)

On the basis of 10% tar production in the process the Baddesley type coal is used

This coal then provides 9613.08 gas heating value in Btu/lb coal

addesley coal ga

| ompositior | MWt | vol% | O2 per mol | mol O2 per mol gas | | | |
|---|---|---|---|---|---|---|---|
| O2 | 44.01 | 6.7 | 0 | 0 | | | |
| lkyls | | | | | | | |
| 2 | 31.9988 | 0 | 0 | 0 | | | |
| O | 28.016 | 25.3 | 0.5 | 0.1265 | | | |
| 2 | 2.0158 | 21 | 0.5 | 0.105 | | | |
| H4 | 16.043 | 1.8 | 2 | 0.036 | | | |
| 2 | 28.013 | 45.2 | 0 | 0 | | 0.578864 | mol air producing mol gas |
| as Mwt | 23.41069 | | | 0.2675 | mol O2 per mol gas | 1.277093 | mol air to burn mol gas |
| | | | | 0.365631 | kg O2 per Kg gas | 1.855957 | mol air used/mol gas |
| leal gas density of producer gas | | | | 1.580041 | kgair/kg gas | 2.296221 | kg air used / kg gas |

0.9882 kg/m^3

).061691 lb/s cuf — d=Mw/0.0224

hysical data

| | | | |
|---|---|---|---|
| ensity of T | 75 | lb/cuf | Perry 6 (1984) |
| | 1200 | kg/m^3 | |
| | 10.01449 | lb/gal | |

nits

cf is volume in cubic feet at 60 Farenheit and 30" Hg — KO 2 (1964)

288.7056 42.2115 0.02369

| ensity | lb/cuf | lb/gal | kg/m^3 | Perry 6 (1984) |
|---|---|---|---|---|
| | 0.062428 | 0.008345 | 1 | |
| | 7.480519 | 1 | 119.8264 | |
| | 1 | 0.133681 | 16.01846 | |

| iass | ton (short - | lb | kg | Perry 6 (1984) |
|---|---|---|---|---|
| | 1 | 2000 | | |
| | | 2.204623 | 1 | |

| ressure | "Hg | N/m^2 | atm | psia | Perry 6 (1984) |
|---|---|---|---|---|---|
| | 1 | 3376.9 | 0.033327 | 0.489775 | |
| | 2.041754 | 6894.8 | 0.068046 | 1 | |
| | 30.00533 | 101325 | 1 | 14.69586 | |
| | | 1 | | | |

| leat value | MJ/m^3 | btu/scf | Perry 6 (1984) |
|---|---|---|---|
| | 0.0373 | 1 | |

| nergy | MJ | Btu | Perry 6 (1984) for steam table values |
|---|---|---|---|
| | 0.001055 | 1 | |

| dry air composition | molar | Mwt | mass comp | kg air per kg component |
|---|---|---|---|---|
| N2 | 0.78084 | 28.0134 | 0.75521 | 1.324134 |
| O2 | 0.20946 | 31.9988 | 0.231406 | 4.321406 |
| CO2 | 0.00033 | 44.01 | 0.000501 | 1994.319 |
| Ar | 0.00934 | 39.948 | 0.012882 | 77.62792 |
| total | 0.99997 | 28.96409 | 1 | |

| Coal type | Moisture | Sulfur | | Heat value | | | | |
|---|---|---|---|---|---|---|---|---|
| | % | % | %dry | Btu/lb | Btu/lbdry | | | |
| Sub bit C | 26 | 0.3 | 0.41 | 8230 | 11121.62 | | | |
| HV bit A | 2.9 | 0.6 | 0.62 | 14170 | 14593.2 | low sulfur coal heating value | | |
| Sub bit B | 22.2 | 0.5 | 0.64 | 9610 | 12352.19 | | | |
| Brown Coa German - R | 55 | 0.3 | 0.67 | 4830 | 10733.33 | | | |
| Sub bit A | 13.9 | 0.6 | 0.70 | 10330 | 11997.68 | SD= | 1295.775 | 0.108169 |
| Meta Anthracite | 9 | 0.7 | 0.77 | 10080 | 11076.92 | Avg= | 11979.16 | |
| LV bit | 2.9 | 0.8 | 0.82 | 14400 | 14830.07 | median | | |
| Anthracite | 4.3 | 0.8 | 0.84 | 12880 | 13458.73 | | 27.86352 | MJ/kg |
| Lignite | 36.8 | 0.9 | 1.42 | 7000 | 11075.95 | | dry base | |
| MV bit | 2.4 | 1.5 | 1.54 | 14490 | 14846.31 | | | |
| Semi anthracite | 2.1 | 1.7 | 1.74 | 13700 | 13993.87 | | | |
| HV bit B | 6.7 | 2.6 | 2.79 | 12390 | 13279.74 | | | |
| HV bit C | 15.4 | 2.9 | 3.43 | 10740 | 12695.04 | | | |

bit=Bituminous
V=Volatility
L=low
M=Medium
H=high

Source: Kirk Othmer vol 4 1949